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ORIGIN OF BANDS IN SANDY SOILS OF THE STONY PLAIN AREA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Origin of Bands in Sandy Soils of the Stony Plain Area" submitted by Gerald M. Coen, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.





## ABSTRACT

Soils characterized by the presence of bands have presented difficulties in classification during the course of a soil survey in the pitted deltaic sandy areas west of Edmonton, Alberta. The bands appear to be finer in texture as well as darker and redder in color than adjacent interband materials; however, they do not meet the criteria set forth for the definition of a Bt, Bh, or a Bf horizon in the Canadian Classification Scheme.

This study was undertaken to determine the nature and origin of the bands as well as the nature and mode of deposition of the surface materials from which these soils developed in order to assist in their classification.

The parent materials in the sampling area, west of Edmonton, Alberta, are pitted deltaic in deposition, consequently fairly large, often sharp knolls with complex slopes are prevalent. Associated with the sharper knolls are the coarser textured materials which generally contain prominent, distinct bands. The smaller, more gentle knolls are usually finer textured and have fine convolute bands in the profiles. A deep "Ae-like" horizon between the Ah horizon and the first band is found in many of the profiles.

For the investigation, three profiles were sampled which generally reflect the more common soils of the area. The bands and interbands were sampled individually in order to be able to compare the laboratory analysis with the field morphological observations. Physical, chemical, mineralogical, and micropedological analyses were conducted in order to characterize the soils under study and assist in their classification.

Analyses indicate that stratification, both textural and mineralogical, is evident to a greater or lesser degree in most of the profiles





in the area. The bands have iron and organic matter contents which are greater than the interbands. These concentrations are considered to be illuvial in origin. There are indications that illuvial clay is also present in the bands. The soils are acidic throughout although they are highly base saturated. Calcium carbonate is generally not evident even at considerable depths. Montmorillonite is by far the dominant clay mineral while illite and kaolinite are found in nearly equal, minor to trace amounts. Chlorite is only rarely found in these soils.

The "Ae-like" material may be aeolean in nature but was not necessarily deposited directly by wind. Texturally this surficial material appears to be similar to that in the lower part of the solum. This surficial or "Ae-like" material is eluviated and is above any illuvial horizon and thus probably should be referred to as an Ae horizon.

The bands appear to be largely pedogenic although they tend to form in geologic strata when such strata are present. None of the bands have sufficient accumulations to be designated as Bf or Bt horizons as set forth by the Canadian Classification Scheme. Although the soils studied do not fit well into any existing category in the Canadian Classification Scheme, they probably fit best in the Dark Grey Forested sub-group of the Podzolic order.



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## I. INTRODUCTION

Soils with bands darker and redder in color than adjacent interband materials have been observed in the Stony Plain area west of Edmonton, Alberta. The origin and nature of these bands have puzzled pedologists for some time. There are two main theories as to the origin of these bands.

- (1) The bands are the result of geologic depositions.
- (2) The bands are the result of pedogenic processes.

Associated with many profiles in the area are deep "Ae-like" horizons extending from the lower Ah horizon downward to the top band. The formation of an Ae horizon of the thickness of the "Ae-like" materials found in these soils is much greater than would normally be expected when compared to adjacent Grey Wooded soils. Thus, some workers have considered this material to be an eluvial horizon while others have felt that it is an aeolean capping or overlay.

The soils are underlain by material described by Bayrock and Hughes (1962) as pitted deltaic. The steep complex slopes and the sandy soils in the area are the result of a delta which formed near the edge of the continental glacier at the close of the last glacial era. Large ice blocks are thought to have ablated from the glacier, and were covered with deltaic deposits before melting away. After the ice had melted, large pits which appear as enclosed basins were left in the area.

Deep, generally coarse textured profiles are common to all the soils which have bands present. The first band generally occurs at depths varying from 20 to 45 inches below the soil surface. Band thicknesses from a fraction of an inch to about 8 inches have been noted. The bands conform to the contour of the soil surface with some exceptions,



and thin branches are often observed migrating toward the surface. Thicker, more distinct bands are generally found in the coarser textured materials while in the finer textured materials thin convolute bands are more common. The coarser textured materials are generally associated with sharp, fairly prominent knolls.

These soils have not yet been officially assigned a series name, although they have been largely separated from other soils by the Research Council of Alberta, Soil Survey, in preparation for the soil survey report soon to be published. The multiple horizons of apparently illuvial and eluvial material as well as the deep Ah and Ae horizons have constituted problems in horizon nomenclature and classification of these soils.

The vegetation in the area is generally considered of the type conducive to moderate podzolic development. Many of the profiles have been noted to have Ah horizons of considerable depth with deep "Ae-like" material below despite the fact that podzolic soils in Alberta that have deep Ae horizons generally have shallow or no Ah horizons present. Thus, some processes or conditions must be different than generally associated with podzolic development.

It was felt that the mode of formation of these bands could be elucidated by conducting physical, chemical, mineralogical, and micro-pedological studies on the band and interband materials and relating the data to field morphological observations.

Aside from the academic interest of this study, it is of considerable value for the soil survey reports to contain accurate information as to the genesis and origin of the soils discussed therein. This type of information tends to promote greater acceptance and use of the reports by other professions. Agronomically, information regarding the cation exchange capacity, per cent base saturation, and amount of organic





matter is always useful. Associated with the considerable depth of "Ae-like" material in many of these soils there may be appreciable weathering with a concomitant loss of valuable fertilizer elements.

The main objectives of this study are:

- (1) To determine the genesis and nature of the bands found in the soils under study in order to assist in their classification.
- (2) To determine the origin and nature of the "Ae-like" material found above the top band of many of the profiles in the sampling area.



## II. LITERATURE REVIEW

### The Development of Pedology

"Pedology presents the soil as a unit in nature; it deals with its origin, formation and distribution through a study of its constitution, its life and dynamics" (Joffe, 1949). It was only in relatively recent times (since Dokuchaev, 1879) that the study of soils became a science, distinct from the other natural sciences, thus allowing the evolution of pedology as a discipline. Pedology occupies a position intermediate between the sciences of animate and inanimate nature.

The animate approach is demonstrated by the agronomist, who considers soil mainly from its nutritive and supportive role for plants. Cameron, Hopkins, and Whitney are best known for their agronomic approach to pedology and thus may be thought to represent this fraction of soil science (Joffe, 1949).

The inanimate approach can be divided into physical, chemical, and geologic. Davy, Schubler, and Wollny studied and discussed soils with a physical discipline bias (Joffe, 1949; Baver, 1959). Workers such as Berzaleus, Liebig, and Thaer evaluated soils from a chemical point of view. Berendt, Braungart, Hausman, Senft, and Werner all considered the study of soil as part of the field of geology (Joffe, 1949).

Because all early workers considered the study of soils as belonging to some existing discipline, the concept of pedology was slow to evolve. The first attempt to treat soil science as an independent science, and soil as a separate formation, was made by Fallou. He stated that "soil is decomposed, more or less disintegrated native rock, with an admixture of organic materials. The rock has changed and metamorphosed in its form and infrequently in its makeup. Soil as such does not therefore belong any





more to the rock formation but is a formation itself."

Fallou criticized the chemical approach to pedology that was adopted by some workers and blamed the utility standpoint for preventing the crystallization of a scientific appreciation of the nature of soils.

Despite his concept of soil as an independent body, Fallou had considerable geologic bias and thus did not grasp the significance of the soil forming processes, hence his ideas on soil as a natural body are not clear. On the other hand, Hilgard used a genetic approach to soils, noting the relations of various soils with different natural conditions and factors of soil formation. While noting that the meteorological conditions in the area largely influenced the type of weathering of the parent rock, he failed to see morphology as a product of the soil forming factors (Joffe, 1949).

The concept that the study of soils is an independent science was first appreciated fully by Dokuchaev (1879). To him is attributed the fundamental thesis that "soil is a distinct and independent natural-historical body". He described soils as "the surface mineral and organic formations always more or less colored by humus, which constantly manifest themselves as a result of the combined activity of the following agencies; living and dead organisms, parent materials, climate and relief". Thus, Dokuchaev appreciated the relation of soil forming factors and did much to crystallize the concept of pedology (Joffe, 1949).

Such Russian workers as Glinka, Sibirtzev, and Zakharov contributed to the rise in appreciation of pedology by contributing to and expounding Dokuchaev's concepts. The West was slower in adopting a pedological approach but when Glinka's volume (a German translation of his lectures) was translated into English by Marbut the concept of pedology developed more rapidly (Joffe, 1949).



Outside of Russia, Marbut was the most prominent worker in the field of pedology. Today his ideas on genesis of North American, South American, and African soils are undoubtedly as far-reaching as those of the most outstanding Russian pedologists. Marbut had only his personal observations and very little pedological data, with which to elucidate his theories and thus his work is considered monumental (Joffe, 1949).

The progress of pedology in North America has probably not been as great as could be expected considering the contributions made by Marbut. However, the science of pedology is beginning to exhibit itself as the basic science from which agronomists, plant scientists, geologists, engineers, clay mineralogists, and others are able to draw worthwhile knowledge.

### Profile Formation

The causes of variations in soil profiles can be divided into two main categories, pedogenic and geologic.

#### Pedogenic

The pedogenic concepts expounded by Sibirtzev (as quoted in Joffe, 1949) and most other workers revolve around the soil forming factors. While not in disagreement with these concepts, Nikiforoff (1959) feels that a more analytical, all encompassing approach to basic research in pedology is necessary. His thermodynamic approach, using energy relationships, is depicted by his statement "Pedogenesis consists of transactions in matter and energy between the soil and its surroundings". The soil is considered by Nikiforoff (1959) as a thermal pool into which flow two streams of energy, solar radiation and energy from radioactive





decay within the earth. The balance of energy from these two sources then governs all soil forming reactions.

The formative reactions for soils in the Podzolic order are of major interest in this study. The name Podzol has its root in the Russian word "Zola" meaning ash (Joffe, 1949). The Podzolic soils have a zone of eluviation and a zone of illuviation. Sometimes eluviation may mainly involve clays resulting in formation of soils with textural B horizons. Such soils within the Podzolic order of the Canadian Classification Scheme are the Grey Wooded and Grey Forested Great Groups of Western Canada and the Grey Brown Podzolic Great Group of Eastern Canada. In parent geologic material generally of lower base saturation, the translocation of sesquioxides and/or humus from the surface to sub-surface horizons is predominant resulting in formation of Podzols and Humic Podzols. There are, of course, all possible intergrades between these two extremes. In the early nineteen hundreds soils fitting, outwardly at least, the description of a Podzol but having alternate bands of dark and light colored materials and/or coarse and fine textured materials, or both, were observed (Wilcox, 1906; Aarino, 1913; and Liesegang, 1923). It is conceivable that many of the forces causing Podzols to form are active in these "banded" soils.

It is evident that the mechanism of eluviation and illuviation in Podzols is complex and, as yet, not fully understood. However, it has been demonstrated that before the movement of materials through the profile becomes appreciable a considerable portion of the exchangeable bases in the upper solum must be replaced by hydrogen ions (Stobbe and Wright, 1959). Once this prerequisite has been met there are several theories as to how the materials are translocated.



## A. Translocation of Sesquioxides

### (a) As an inorganic cation

One possible mechanism of sesquioxide movement is as inorganic cations. The close connection between the movement of sesquioxides and the decomposition of organic matter has long been recognized. It has been suggested that the acidity created by the decomposition products of organic matter brings about solution of the sesquioxides with their subsequent deposition in lower horizons due to higher pH (Deb, 1950). However, the solubility of ferric iron at a pH above 3.5 is negligible and because Podzols seldom reach a pH this low, movement in the inorganic form seems unlikely (Deb, 1950; Stobbe and Wright, 1959).

Under reducing conditions ferrous iron stays in solution at pH ranges normally found in many Podzols. Thus, it is possible that in gleyed or ground water Podzols the iron moves down as the ferrous form in the saturated period of the year and oxidizes during the unsaturated period (Deb, 1950; Stobbe and Wright, 1959).

### (b) As inorganic sols

Mattson and Koulter-Andersson (1942) as quoted by Deb (1950) has proposed the movement of iron as a positively charged iron oxide sol. Deb (1950) believes that this process is impossible unless the A horizon is shown to be positively charged so that the iron oxide sol will move through it into the negatively charged B horizon with resulting precipitation. Since no one has demonstrated a positively charged A horizon, Deb (1950) discounts this theory.

Reifenberg (1938) as quoted by Deb (1950) suggested the movement of iron as a silica-protected iron-oxide gel. Barbier (1938) found that thirteen parts of silica are needed to peptize one part of ferric oxide sol.





Therefore Deb (1950) discounts this explanation since the high ratio of silica to iron would result in a net enrichment of iron in the A horizon.

(c) As sesquioxide-humus sols

Aarino (1913) was the first to suggest that hydrated free oxides are transported as negatively charged humus protected sols. Humus may carry with it from three to ten times its own weight in iron oxide, varying with different fractions of organic matter (Deb, 1950). If the sesquioxide-humus theory is to be accepted it is necessary to assume either a divalent cation or a microbial precipitation in the B horizon. Since in many Podzols the supply of divalent cations is so low that it is doubtful that precipitation would occur, Deb (1950) states that a microbial mechanism of deposition is most likely.

Mattson and Gustafsson (1934) and Mattson and Koulter-Andersson (1942) explained the formation of sesquioxide complexes and their movement and deposition by the theory of isoelectric weathering. This theory, although it has many attractive features, demands a significant pH gradient with depth in the profile, a condition which is not found in many Podzols (Stobbe and Wright, 1959).

(d) As soluble metal-organo complexes

Probably the most accepted mechanism for sesquioxide movement is as soluble metal-organo complexes. The compounds can exist as complex ions or as chelates.

Many workers (Jones and Wilcox, 1929; Rode, 1937; Gallagher, 1942; Gallagher and Walsh, 1943; Jackson and Sherman, 1953) have suggested that relatively simple organic acids complex the sesquioxides. The Russian workers Alekandrova (1954) and Kononova (1956) suggested that the sesquioxides may be complexed with humic acids or humates while





Yarkov (1956) attributed the complex formation to fulvic and other low molecular weight acids with ferrous, not ferric, compounds. Yarkov (1956) suggested that periodic anaerobic conditions allow the formation of the ferrous compounds.

Aqueous extracts of many vegetative materials have the ability to reduce iron and then complex it into a stable form (Bloomfield, 1953, 1954; Schnitzer and DeLong, 1955). The reduction of ferric iron occurs even under aerobic conditions. The reduction and solution of ferric oxides has been attributed to the action of carboxylic acids and polyphenols, reduction being effected primarily by the latter compounds (Bloomfield, 1957).

The method of deposition of the sesquioxides from complexes is uncertain. Yarkov (1956) believes the deposition is due to oxidation of the ferrous compounds and destruction of the mobile organo-complexes by micro-organisms. Similar mechanisms have been suggested by Starkey and Halvorson (1927) and Deb (1950). Unlike Yarkov (1956), Kononova (1956) believes the mobility of the complexes and their immobilization depends on the reaction of the medium, the concentration of the humic materials, and the oxidation reduction conditions.

Present research suggests the possibility that naturally occurring chelating substances play a large part in sesquioxide movement. Schnitzer and DeLong (1955) as well as Swindale and Jackson (1956) suspected chelation in Podzols but were unable to definitely prove it. Profiles, similar to those of Podzols, were produced by Wright and Levick (1956) and Atkinson and Wright (1957) by leaching a column of calcareous sand with E.D.T.A. More recently Wright and Schnitzer (1963) were of the opinion that under natural conditions the fulvic acid is the dominant ligand affecting sesquioxide movement in the podzolization process. Their



analyses suggest that fulvic acid consists of an aromatic "nucleus" to which carboxyls, hydroxyls, and carbonyls are attached as the main functional groups. According to Wright and Schnitzer (1963) there is a strong possibility that on its path down the profile the fulvic acid initially forms a water-soluble multidentate chelate with metals such as iron and aluminum, etc., and that precipitation of these metal-organic complexes lower in the profile is effected by further reaction with the same metals and by extremely small amounts of ionic  $\text{Ca}^{++}$  and/or  $\text{Mg}^{++}$ . In 1964 Schnitzer and Skinner demonstrated further evidence to support this theory.

Bloomfield (1955b) noticed that drying and/or aeration may bring about precipitation of sesquioxides. He also noted (1955a) that the immobilization of sesquioxides is associated with the sorption of the complexes on the mineral soil materials. The reprecipitation process is not fundamentally one of reoxidation, although it is favored by oxidizing conditions.

#### B. Translocation of Humus

Under some conditions the amount of humus precipitated in the B horizon becomes sufficiently large to meet the criteria set forth for a Bh horizon as defined by the Canadian Classification Scheme. The infiltration of humus must be considered as part of the podzolization process. With regard to the foregoing discussion, if the sesquioxides move down as organic complexes, then immobilization of the complexes result in a concentration of organic matter as well as sesquioxides. This concentration will, however, seldom be of sufficient magnitude to constitute a Bh horizon. Stobbe and Wright (1959), through morphological observation, suggest that a large percentage of the organic matter moves to the B horizon in solution and colloidal suspension. They have observed





after rains large masses of dark organic matter passing through the Ae often in a wavy manner. When this organic matter is leached down to the layer where a concentration of humus and sesquioxides occur, it is filtered out. Periodic drying stabilizes the organic matter which then resists further movement.

### C. Translocation of Clays

The terms "lessivage" (Duchaufour, 1960) and "illimerization" (Fridland, 1958) have been commonly used to designate clay translocation as opposed to podzolization or sesquioxide movement. Considerable research has been directed towards the elucidation of mechanisms of sesquioxide movement. However, less research has been done on the mechanisms of clay movement.

Several persons including Wright, Leahey, and Rice, 1959; Pawluk, 1960, 1961; Antipov-Karatayev, 1961; Gorbunov, 1961; Radeke and Westin, 1963; St. Arnaud and Mortland, 1963; Harpstead and Rust, 1964 have reported clay movement in the formation of a textural B horizon. Clays are probably moved by a leaching action of the acid decomposition products of forest vegetation (Pawluk, 1960). Duchaufour (1960) feels that water soluble organic materials favor and maintain dispersion of the clay and thus are one of the main factors in "lessivage". Further, he feels that gravitational water is the agent essential to "lessivage" in that it carries the dispersed complexes mechanically.

Fridland (1958) suggested three methods by which the clay minerals may be stabilized in suspension:

- (1) organic substances,
- (2) colloidal silica, and
- (3) adsorbed hydrogen onto the surface of the clay micelle.



Since there is often an enrichment of silica in the textural horizon, Fridland (1958) believes that logically a mechanism involving colloidal silica should be favored.

A method by which silicate clays may be translocated from the A to the B horizon in soils at a relatively high pH has been proposed by Pallmann (1943) as quoted by Cline (1949). As evidence that such processes may be operative, it can be shown that (1) clays in the slightly acid Ae horizon of Grey Brown podzolic soils of New York go into stable suspension in water, (2) those in the weakly alkaline or neutral B do not, and (3) suspensions of clays from the Ae are flocculated by the addition of a suspension from the B horizon.

According to Bailey et al. (1957) there is a good possibility that Grey Wooded soils form on clay soils, Podzols form on sandy soils, and intergrades on soils of intermediate texture under similar climatic conditions.

The difficulty which Schnitzer and Gupta (1964) experienced in separating organic matter from mineral material in Grey Wooded soils suggests there is considerable affinity between the clay and the organic material. This may be taken as support for movement as an organic-clay complex.

From the literature there is evidently some doubt as to the exact mechanism of clay movement and deposition in the soil. More research is required before it will be possible to say, with much assurance, by what mechanism the clay moves.

Some question still exists as to whether or not these methods of movement and deposition of organic matter, sesquioxides and clay are active in soils with clay-iron bands. When found, these bands are commonly observed in sandy materials at depths from two to eight feet,





each band being convolute in nature, and from a fraction of an inch to eight inches in thickness. They are easily distinguished since they are finer textured and/or brighter and more reddish in color than the matrix material (Wurman et al., 1959). The bands may be due to the pedogenic processes of illuviation and eluviation. However, they may also be due to geologic stratification.

One mechanism of formation of bands in soil has been thought to be similar to Liesegang rings since both band-formation in artificial gells and those found in soils appear to be similar and may be due to a periodic precipitation mechanism (Liesegang and Watanabe, 1923). Folks and Riecken (1956) in a study of band formation in soils of Iowa stated that the bands were mainly genetic in character. They found that after the concentration of iron in a complexing solution reached a given level, depending upon the concentration of iron in the soil, a precipitation reaction occurred. They felt that the iron moved down the profile with the percolating solution to a point where it had complexed the critical amount of iron. Then the precipitation reaction occurred releasing the complexing agent which then proceeded down the profile complexing more iron. The immobilization of the iron would occur repeatedly down the profile whenever the critical concentration was reached. Band formation is further accentuated by subsequent solution in the interband region and immobilization in the band region. Oxidation and reduction is not considered by Folks and Riecken (1956) to be involved in the band formation. They also felt that once the iron bands formed, the clay moving through the soil flocculated when coming in contact with the band, thus forming a clay-iron band.

Wurman et al. (1959) identified three types of clay-iron bands.

- (1) Pedo-petrogenetic: those formed as a result of the interaction of an original stratification of the parent material and modification caused





by genesis of the profile.

- (2) Pedogenetic: those formed only due to genetic changes in the profile.
- (3) Petrogenetic: those due only to original stratification of the parent rock.

He postulated several possible mechanisms by which the increase in free iron, clay, and colloidal organic matter could have occurred:

- (1) Individual movement of the three components,
- (2) An organic-iron complex moving independent of silicate clay,
- (3) The movement of a clay-iron-organic matter complex as a unit,
- (4) The formation of one or more of these components in situ.

From the previous discussion on sesquioxide and clay movement, it is unlikely that they move as individual entities. The movement of an iron-organic matter complex and a clay-organic matter complex is feasible. However, there seems to be no reason for not having a complex of clay-iron-organic matter move as a unit. In fact, Wurman et al. (1959) found quite strong evidence for this mechanism.

The formation of appreciable clay or free iron in situ is unlikely due to the high amount of quartz and K-feldspar in the sand fraction (Wurman et al., 1959).

The deposition of translocating materials may be brought about by the following agents (Wurman et al., 1959):

- (1) Deposition by lack of water to flush the materials any farther, or withdrawal by evapo-transpiration. (Microscopic fabric studies support this hypothesis.)
- (2) The presence of lime causing flocculation of clay complexes.
- (3) Mutual flocculation of free iron oxide and clay due to changes in redox conditions and/or pH.



According to a suggestion made by Bartelli and Odell (1960) when a finer textural layer overlies a coarser textured layer, water will penetrate to the boundary between the two and then accumulate before entering the coarser layer. They feel that at this point there will be a deposition of clays carried by suspension. This mechanism may explain the pedo-petrogenetic bands mentioned earlier.

DeMent (1962) suggested that the bands he observed in loessal soils of Alaska were the result of frost action that caused microscopic segregation of mineral grains. He believed that the clay in the bands was largely inherited and only a small portion was illuvial in origin.

In a laboratory study McKeague and Bentley (1960) leached a clay loam parent material, mixed with 95 per cent sand with distilled water percolated through aspen leaves. The profiles developed textural bands without removal of carbonates or appreciable change in any other ion concentration. Thus, possibly the textural bands form first with subsequent iron and organic matter deposition.

Although horizon development has been attributed to pedogenic forces, the nature of these horizons may often reflect stratification in the parent geologic material from which soils are formed. The presence of strata in a soil profile often complicate the pedogenic study of soils, since it is difficult to reconstruct a concept of the original nature of the material from which the soil develops.

There are several different mechanisms which may be responsible for the occurrence of stratified parent materials. Materials can be transported and deposited by the atmosphere, by water, glaciers, and gravity (Twenhofel, 1950). The movement of materials by gravity is of little importance on the prairies, except on erosion slopes of river banks, and thus will not be dealt with further.





The deposition of water or wind transported material onto surfaces of glacial deposits is of common occurrence and where the overlying deposits are relatively thin, the soil solum may develop from both materials. The separation of these two types of deposits is generally relatively simple since the former occurs as stratified deposits while the latter does not.

There are generally three principal reasons for variations among stratified deposits problematic to the soil scientist investigating genesis of the soil solum. Firstly, an aeolean material may be deposited on an alluvial lacustrine material. Also, the aeolean material may be deposited either directly onto the alluvial or lacustrine material or the wind may deposit its materials on the water surface of laking basins (Twenhofel, 1950).

Secondly, the variations in wind velocity and direction may result in stratifications within aeolean deposits as such. According to Twenhofel (1950) the size of the particle varies with the wind velocity and thus a change in velocity might result in a stratification of the deposit. A change in the direction of the wind may alter the source materials which may be of different mineralogical composition resulting in a mineralogical stratification.

Thirdly, stratification may occur in profiles of totally alluvial or lacustrine origin. Transportation of materials by traction, suspension, and colloidal suspension sorts the sediments into three grades. Beach sands on lake and ocean shores are graded by the action of the waves (Twenhofel, 1950). In the deeper parts of standing bodies of water the colloidal materials are deposited by a change in temperature or by the action of electrolytes and colloids of opposite charge. In fresh water, deposition from suspension and colloidal suspension may result in varves



consisting of clays and silts. The summer portion of a varve is lighter in color, coarser in texture, and thicker than the winter portion. The winter portion generally consists of fine clay.

Traction and suspension in streams and rivers also causes considerable sorting resulting in stratification. According to Twenhofel (1950) particles less than fine sand and greater than colloidal size behave according to Stoke's law in still water. Thus, even in fast moving water the individual forces acting according to Stoke's law would be superimposed on those carrying the particles laterally, resulting in segregation.

### Techniques for Evaluating Band Development in Soil Profiles

#### Pedologic Methods

The morphology of the soil profiles often suggests a possible genesis for clay-iron bands. Observations made by Wurman et al. (1959) show that clay-iron bands are in some cases parallel to geologic strata and in other cases the bands cut across the geologic strata. These bands are often discontinuous. In cases where the bands transgress geologic strata there must be some pedogenic forces active. It is felt that useful information may be derived from following individual bands horizontally for some distance to gain an appreciation of their relationships to each other and to the geologic strata with which they are associated.

A determination of free iron oxide has been used by several workers (Folks and Riecken, 1956; Wurman et al., 1959; Pawluk, 1960, 1961; Lavkulich, 1963; Arshad, 1964) to provide an indication of weathering and iron movement and deposition within the profile. The same people have used mechanical analysis to determine clay content in different horizons and thus indicate clay movement as a factor in profile development.





Estimates of organic carbon have been used to study profile development (Pawluk, 1960; Lavkulich, 1964). Organic carbon provides some idea of the amount of organic materials moving through the soil and their distribution in the soil.

A mechanism commonly used to explain the accumulation of translocated sesquioxides (Stobbe and Wright, 1959) is precipitation by divalent ions. Clay-iron bands may form through precipitation at the first concentrations of free lime as evidenced by Wurman et al. (1959). Thus the determination of free lime (Wurman et al., 1959; Lavkulich, 1964) and cation exchange capacity (Wurman et al., 1959; Pawluk, 1960; Lavkulich, 1963) should prove useful in any profile evaluation.

#### Micropedologic Methods

Kubiena (1938) states that nearly every occurrence in a soil has left its picture in the fabric, and that it only need be interpreted. Microscopic studies especially using thin sections with the petrographic microscope provide possibly the most important tool with which to study fabric, and hence aid in its interpretation. Brewer (1964) states that the kinds of soil forming processes that have been operative can be inferred directly from structure and fabric analysis if sufficient background data are available.

Strongly optically oriented clay films and layers in the B horizon have been considered by several people, including Brewer (1956), Minashina (1958), Grossman et al. (1959), Buol and Hole (1959, 1961), and Harpstead and Rust (1964), as indicative of clay illuviation in soil profiles. However, Minashina (1958), Parfenova and Yarilova (1958), Buol and Hole (1959), and Harpstead and Rust (1964) felt that oriented clay concentrations are possible without illuviation. Brewer (1956) in





agreement with the foregoing concept suggested oriented clay concentrations may result from native residual and/or synthesized clay becoming optically oriented through wetting and drying as well as through pressure exerted by the forces of freezing and thawing. He felt that soil properties such as bulk density, porosity, and particle size distribution should be taken into account when attempting to assess the genesis of "clay skins". Those formed by in situ weathering, for example, show little or no change in bulk density or porosity. Brewer (1964) stresses that cutans<sup>1</sup> of illuvial clay which generally have sharp boundaries, are found on conducting voids and are strongly oriented often with isotropic inclusions.

Other workers including Kubiena (1938), Frie and Cline (1949), McMillan and Mitchell (1953), Karpachevskiy (1960), Mathieu (1960), Acton and St. Arnaud (1963), and Pettapiece (1964) have observed soil fabric in an attempt to correlate fabric with clay movement. If the fine materials are carried out of the eluvial horizon and deposited in the illuvial horizon then the fabric in the eluvial horizon would likely not be very dense nor would cutans be prominent. Conversely, the fabric in the illuvial horizon would be denser than in the eluvial horizon, and probably the parent material. The illuvial horizon would likely show cutans. This premise is in accord with most workers and agrees quite closely with recent work on Dark Grey and Grey Wooded soils in Manitoba (Pettapiece, 1964).

From the foregoing discussion it seems possible that a micro-pedological approach to the study of clay-iron bands may aid considerably in the elucidation of band formation. Micromorphology differs from macromorphology not only in size but also in diagnostic features and

<sup>1</sup> See page 22 for definition.



concepts of descriptions. This being so, a short discussion of micro-morphological terminology is included. The terminology used is that of Brewer (1964) unless otherwise noted.

"Skeleton grains of a soil material are individual grains which are relatively stable and not readily translocated, concentrated or reorganized by soil forming processes; they include mineral grains and resistant siliceous and organic bodies larger than colloidal size."

"Plasma of a soil material is that part which is capable of being or has been moved, reorganized, and/or concentrated by the processes of soil formation. It includes all the material, mineral or organic, of colloidal size and relatively soluble material which is not bound up in skeleton grains."

"The soil fabric is the physical constitution of a soil material as expressed by the spatial arrangement of solid particles and associated voids."

Names, proposed by Kubiena (1938) and revised by Brewer (1960, 1964) for various observed soil fabrics were also used in this study. These are:

(1) Porphyroskelic. "The plasma occurs as a dense groundmass in which skeleton grains are set after the manner of phenocrysts in a porphyritic rock."

(2) Agglomeroplasmic. "The plasma occurs as loose or incomplete fillings in the intergranular spaces between skeleton grains."

(3) Intertextic. "The skeleton grains are linked by intergranular braces or are embedded in a porous groundmass."

(4) Granular. "There is no plasma, or all the plasma occurs as pedological features."





Although not complete, it was the opinion of Brewer (1964) that these are sufficient for present observations.

A few more definitions of the micropedological terminology used in this discussion follow:

A ped is "an individual natural soil aggregate consisting of a cluster of primary particles and separated from adjoining peds by surfaces of weakness which are recognizable as natural voids or by the occurrence of cutans."

Pedological Features. "Recognizable units within a soil material which are distinguishable from the enclosing material for any reason, such as origin (deposition as an entity), differences in concentration of some fraction of the plasma, or differences in arrangement of the constituents."

Brewer (1964) has discussed fully the many different pedological features. However, for the purposes of this discussion cutans are possibly the only feature requiring clarification. A cutan is described as "a modification of the texture, structure, or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or in situ modifications of the plasma; cutans can be composed of any of the component substances of the soil material."

The features described as "clay skins" frequently contain varying amounts of materials other than clay minerals such as organic matter and sesquioxides (Kubiena, 1938; Bartelli and Odell, 1960; Gorbunov, 1961; Guadusov and Dyazdevich, 1961). Therefore, the term "clay skin" as defined by Buol and Hole (1961) is felt by Brewer (1964) to be inappropriate and is included as one of the categories under the general heading of cutans.



## Identification of Profile Stratification

It is of considerable importance to the pedologist to know whether or not layering in a profile is pedological or geological in origin. In addition it is of interest to him to elucidate the nature of the processes involved. There are many approaches by which this may be done, each process contributing data that can either substantiate or disprove a given hypothesis.

### A. Mechanical Analysis

Mechanical analysis have been used to identify profile discontinuities. Doeglas (1946) showed that the shape of cumulative curves provide information about the origin and nature of geological deposits. Size alone may exclude certain origins; for example pebbles, gravel, or clay generally exclude aeolean deposits. In materials transported by wind the size fractions greater than medium sand lag behind because most winds do not possess enough energy to move them efficiently by either suspension or traction. Fine materials remain suspended for large distances and are not deposited as quickly as the fine sands and coarse silts. Thus, aeolean deposits are generally quite uniform. River deposits are quite heterogeneous with a much wider size range of materials evident (Twenhofel, 1950).

Since 1946 there have been several attempts to perfect the cumulative curve technique using statistical probabilities (Inman, 1952; Harris, 1958; Mason and Folk, 1958; Folk, 1962; Friedman, 1962). When the log of the diameter of the particle is plotted against the frequency on graph paper a normal curve or one of the family of curves derived from normal distributions results (Inman, 1952). Most of the recent work has involved measures of "goodness of fit" to the normal





curve. Mason and Folk (1958) were able to separate beach sand, dune sand, and aeolean sand by measures of skewness and kurtosis of the normal curve obtained from mechanical analysis data. Folk (1962) also states that in the sand sized fractions the use of a settling tube rather than sieves for mechanical analysis is not accurate enough to separate uniform distributions.

Arnold and Cline (1961) used cumulative curves to study the origin of surficial deposits in New York. The method used here was essentially the same as proposed by Doeglas (1946) and is probably sufficient for many soils problems.

#### B. Roundness and Shape

According to Twenhofel (1945) roundness expresses a measure of the curvature of the corners and edges of pebbles and sand grains. Shape designates the form of the particle, entirely independent of whether edges or corners are sharp or rounded. On the basis of considerable literature review, Twenhofel (1945) expresses the opinion that the shape and roundness of sands is of little if any value in indicating their origins or modes of deposition. However, a separation of two deposits is possibly aided by roundness and shape because of the preferential abilities of aqueous and atmospheric media to move particles varying in these criteria (Shepard and Young, 1961). It must be remembered, though, that a wind transported sand may be deposited in water, with roundness and shape indicating wind while stratification indicates water (Twenhofel, 1945).

#### C. Grain Frosting

Grain frosting has been used to indicate aeolean materials. According to Twenhofel (1945) frosted grains less than 0.5 mm. in





diameter testify to aeolean transportation but not necessarily to wind deposition. Wind abraided grains of less than 0.5 mm. are frosted like ground glass while water abraided grains of the same size are polished and glassy.

Comments regarding roundness, shape and grain frosting assume the sands to be of similar hardness to quartz.

#### D. Cross Bedding (cross lamination)

If sufficiently perfect cross bedding is present, it may be of value in the identification of materials of aqueous or aeolean origin (Twenhofel, 1950). Cross bedding may be found associated with the deposition of sands in any environment. Both Twenhofel (1950) and McKee (1957a, 1957b) agree that the two types of bedding are different enough that they are indicative of the mode of deposition.

#### E. Mineralogical Analyses

Mineralogical studies of light and heavy minerals in the sand fraction as well as the clay minerals can be used to support or disprove the hypothesis of a profile discontinuity in the solum. Grossman et al. (1959) in applying this technique found one of the problems of the method was to distinguish between normal changes in mineralogy, with depth, due to weathering and those due to deposition. It should be noted that a difference in mode of deposition is possible without a difference in mineralogy, and a difference in mineralogy is not always due to a difference in the mode of deposition, but may be the result of a different source of materials.



## Previous Studies in the Sampling Area

### Geologic

The last glaciation of the Edmonton area is thought to have taken place around 31,000 years ago (Bayrock and Hughes, 1962). The deglaciation of the area was likely stagnation rather than frontal retreat (Bayrock, 1958; Bayrock and Hughes, 1962). With the stagnation and melting of the ice, glacial Lake Edmonton formed. Hughes (1958) feels that the main inflow of water into the lake was to the west of Edmonton where it formed deltas. With the draining of Lake Edmonton, probably through the Gwynne outlet, the deltas were eroded. The pits dotting the surface of the area, where the remains of the eroded deltas are, probably formed by the deposition of the sediments around ice blocks with subsequent melting of the ice to form the pits. Hughes (1958) referred to these materials as "inwash" and likens them to the "silt tills" described by Collins and Swan (1955). Bayrock and Hughes (1962) prefer the term "pitted deltaic". Collins and Swan (1955) in their map of the St. Ann area have called the parent materials in the sampling area "silt tills", thus the origin of the materials under study are related to the origin of the deltaic materials discussed previously.

### Soils

A soil survey of the St. Ann Sheet was published in 1930 by Wyatt, Newton, and Mather. The mapping was carried out using a four digit system. The map indicates that the sandy loam to loamy sand soils in the sampling area fit somewhere between Chernozemic Black and Podzolic Grey Wooded soils of the Canadian Classification Scheme. Remapping of the area by the Alberta Research Council, Soil Survey, is presently underway. Their work to date is in agreement with the work of Wyatt et al. (1930).





### III. MATERIALS AND METHODS

#### Materials

The climate of the sampling area west of Edmonton is continental, characterized by relatively warm summers and cold winters. The mean summer temperature, May to September inclusive, is 56°F. July is the warmest month averaging 61.5°F. The mean winter temperature, November to March inclusive, is 16°F. Extreme winter lows are rarely below -40°F. and extreme summer highs are rarely greater than 90°F. The average frost free period (above 32°F.) is about 100 days with extreme variations from about 50 to 150 days.

The mean annual precipitation is 17 to 18 inches. About 50 per cent of this precipitation falls in June, July, and August. Approximately 70 per cent of the precipitation falls as rain, the remainder as snow. The average annual snowfall is just over 50 inches.

Wind velocity in the area averages just under ten miles per hour, with little variation throughout the year. The dominant wind direction is from the northwest. During the growing season 60 per cent of the possible hours of sunshine are received. The area can be considered between dry and moist sub-humid (Bowser et al., 1962).

The sampling area is a typical forest-parkland transition area. Parkland is described by Moss (1955) as a mosaic of prairie patches and aspen groves, with the prairie occupying the drier situations and aspen the more moist sheltered places. Presumably in the forest-parkland transition the aspen groves would be relatively more frequent. In this area the aspen groves did dominate the landscape, as far as it is possible to judge with the large amount of cultivation in the area



today. Some of the more prominent native species in the area are:

- (1) Aspen poplar (Populus tremuloides)
- (2) Balsam poplar (Populus balsamifera)
- (3) Willow (Salix species)
- (4) Dogwood (Cornus stolonifera)
- (5) Snowberry (Synphoricarpus occidentalis)
- (6) Common wild rose (Rosa woodsii)
- (7) Reed grass (Calamagrostis species)
- (8) Rye grass (Elymus species).

The soils studied comprise three profiles developed in coarse textured eroded, pitted deltaic materials west of Stony Plain in central Alberta and are associated with glacial Lake Edmonton. The classification of these soils is presently under study by the Research Council of Alberta, Soil Survey. It is generally believed these soils will probably fall either in the Podzolic Order, under the Grey Wooded or Grey Forested Great Groups or in the Chernozemic Order, under the Dark Grey Great Group as set forth in the Canadian Classification Scheme.

The soils are characterized by heavier textured and/or brighter colored bands in the region normally occupied by the B horizon of the profile. The bands run through a coarser textured and/or lighter colored matrix. In association with these soils, fairly sharp knolls or humps are often found. These are usually composed of sandy material to at least 15 to 20 feet. Smaller, less prominent humps often have finer textured material near the surface. The widest most distinct bands form in the first instance while less prominent and more often narrow bands form in the latter instance. In general, if the bands are followed horizontally for some distance they conform to the shape and slope of the hill.



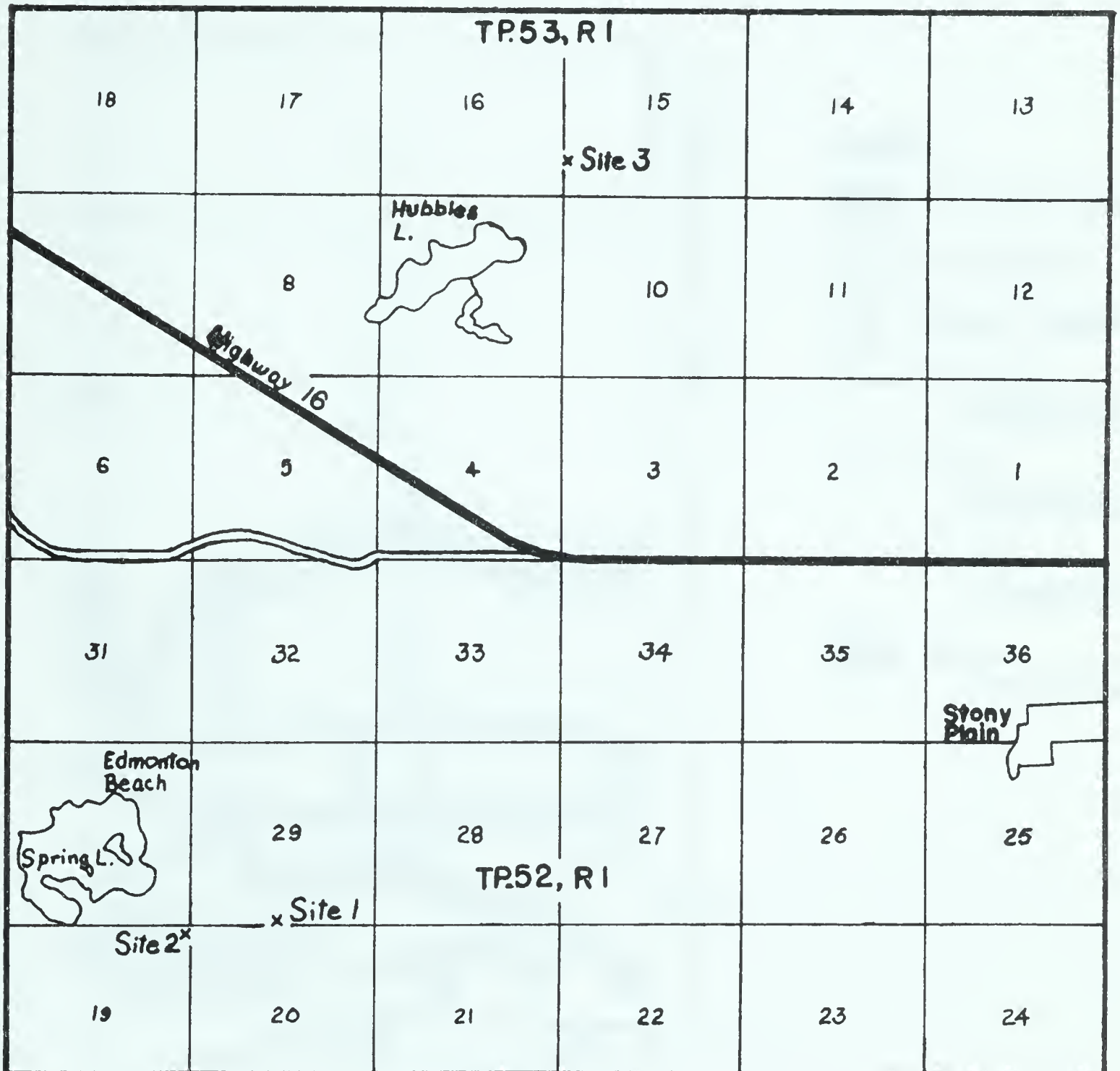


Figure 1 - Map showing sampling sites in the Stony Plain area.





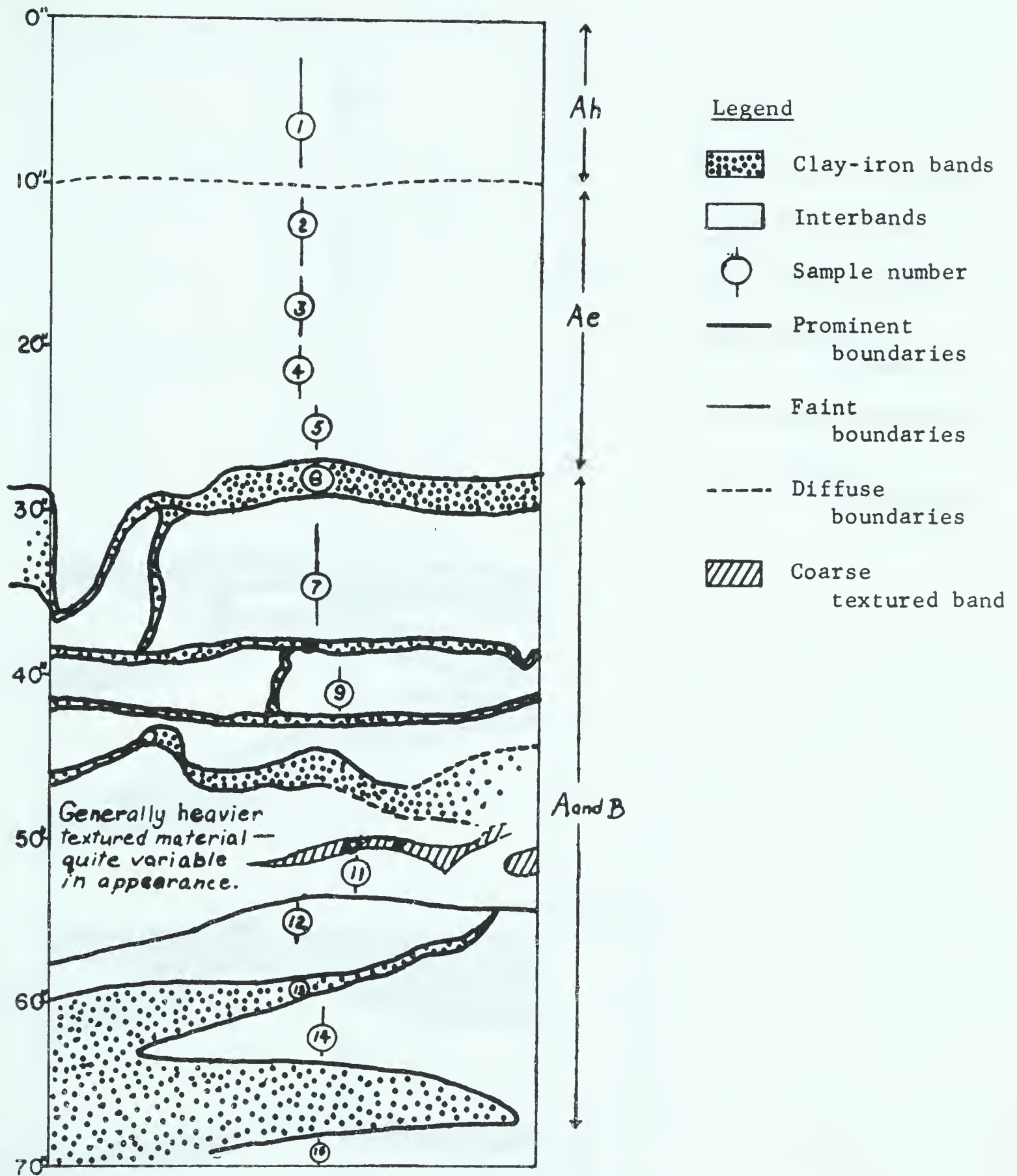


Figure 2 - Scale drawing of Site 1 showing band and interband regions.



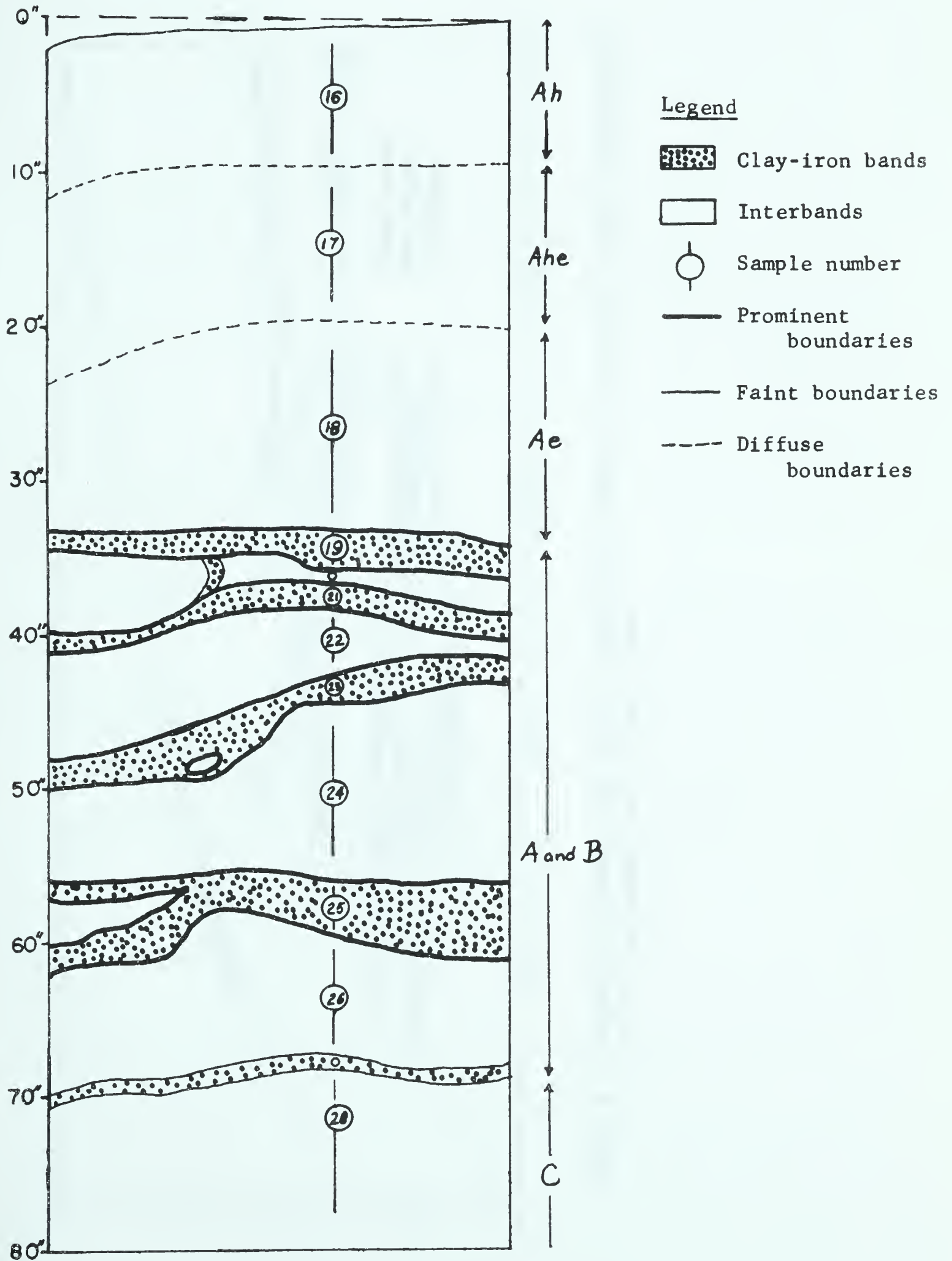


Figure 3 - Scale drawing of Site 2 showing band and interband regions.





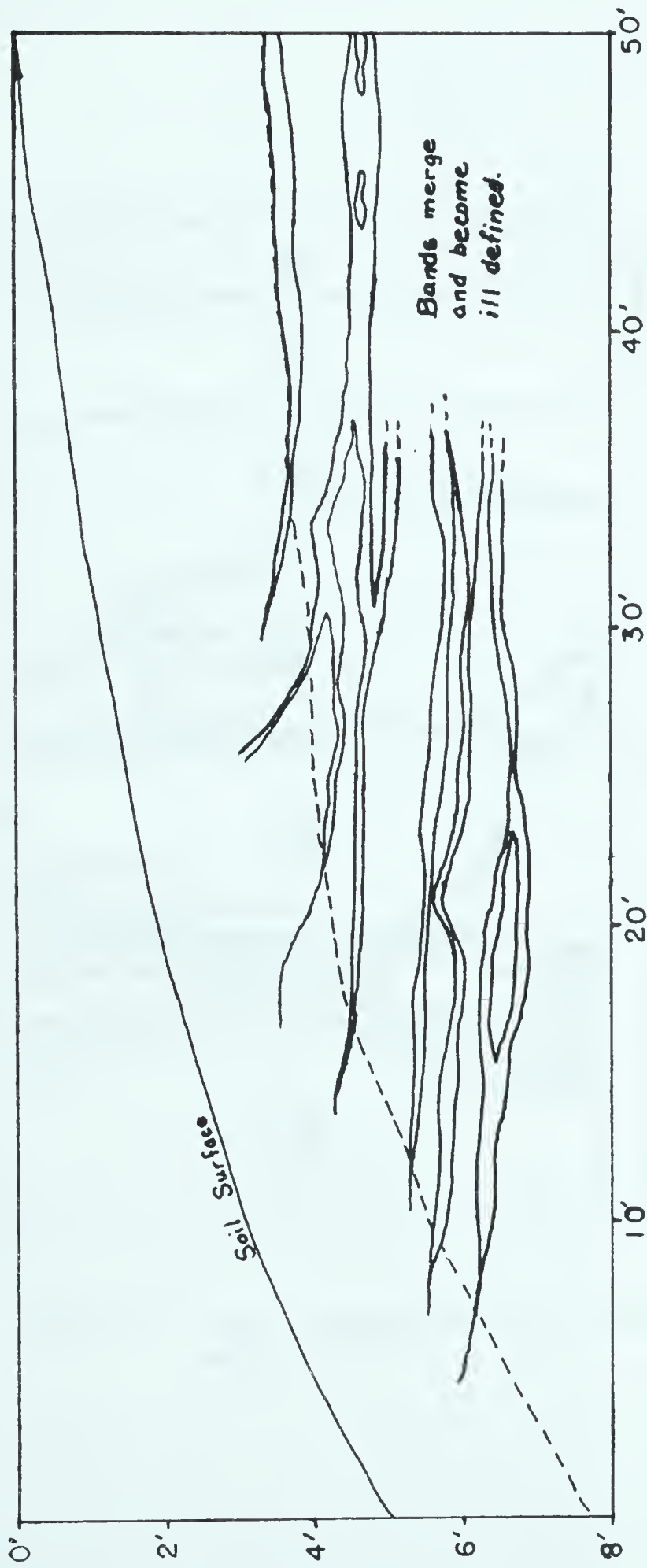


Figure 4 - Schematic drawing near Site 2 indicating nature of the bands, their relationship to the topography and to each other.



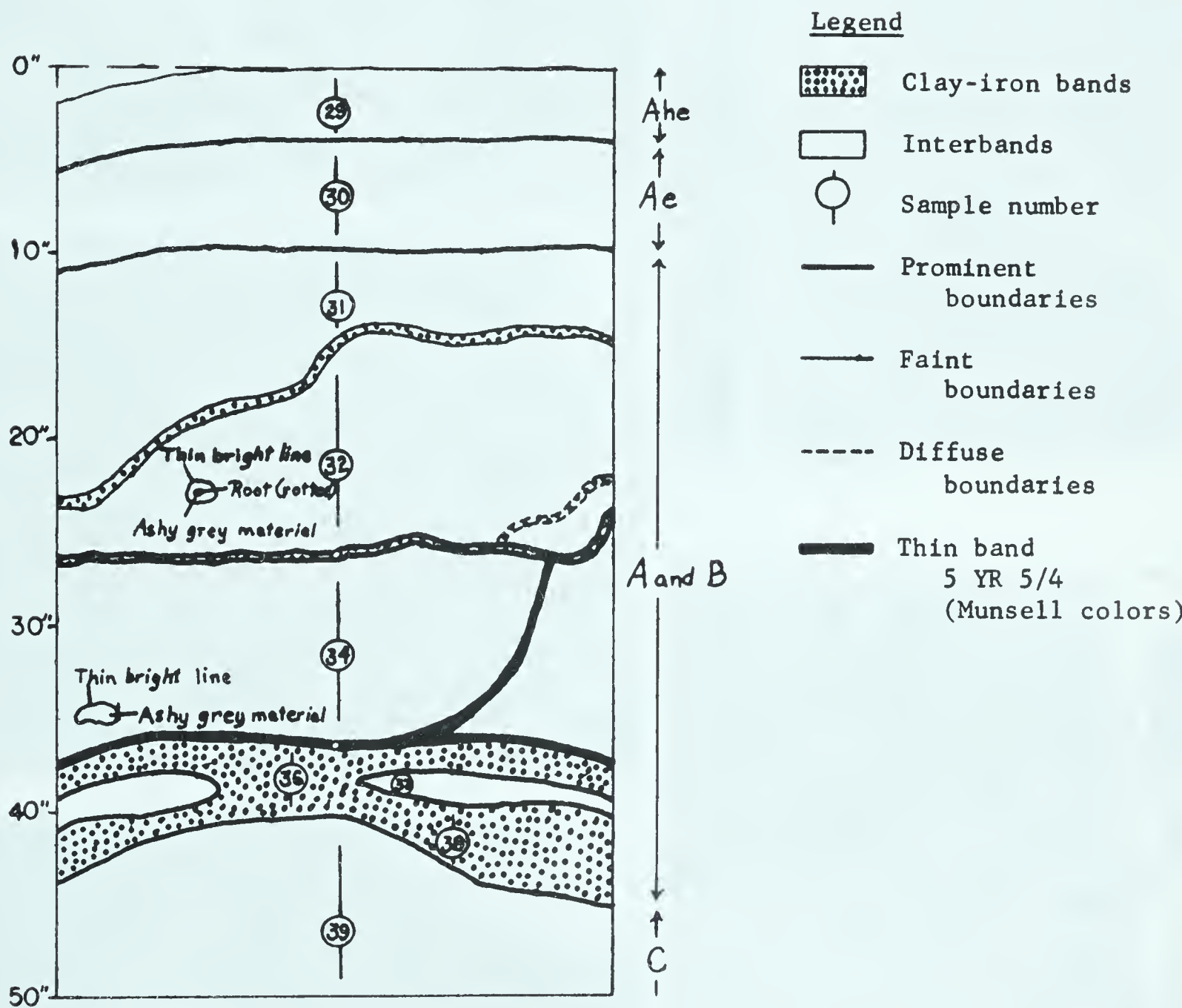


Figure 5 - Scale drawing of Site 3 showing band and interband regions.





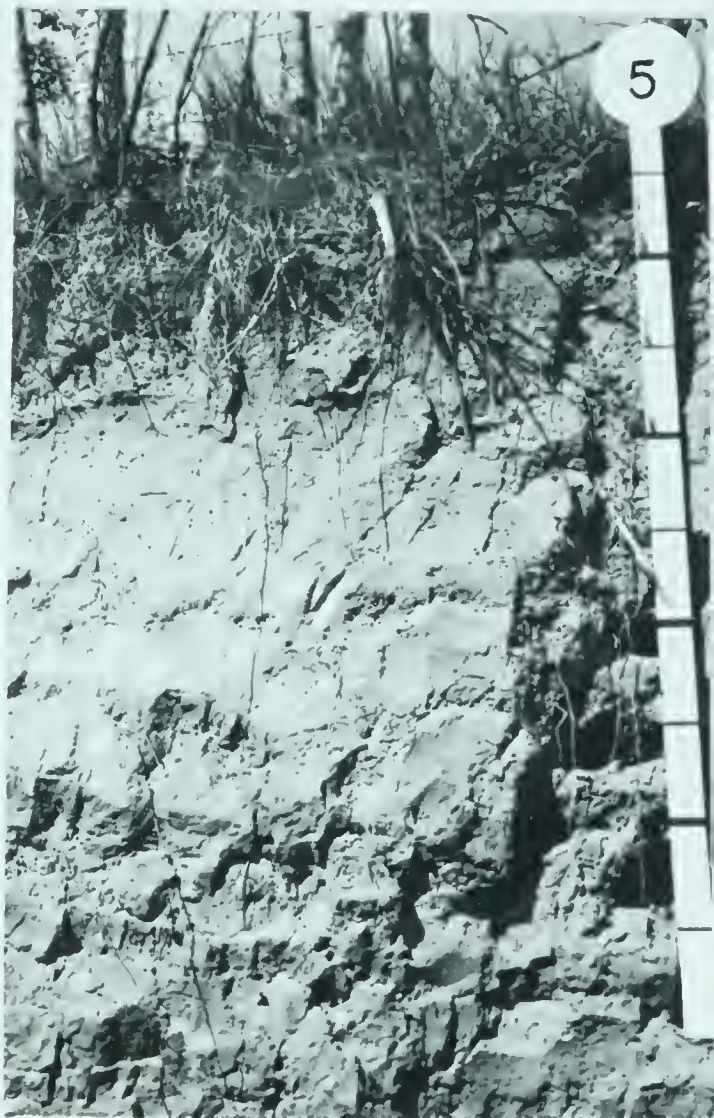
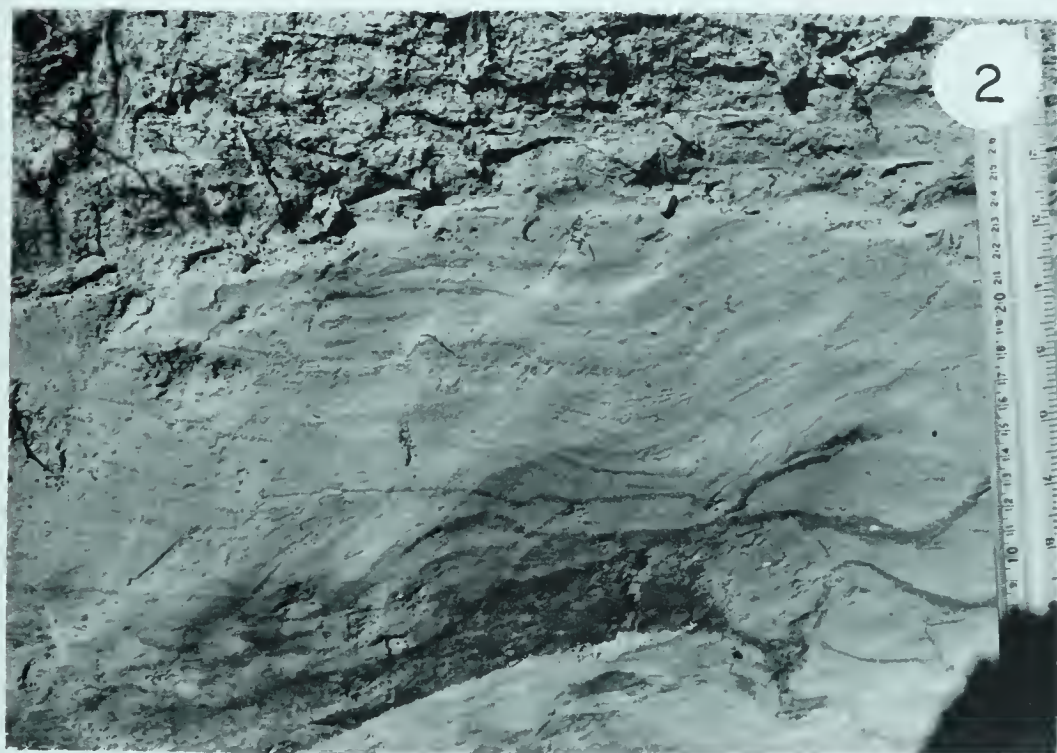


Plate 1. Some photographs of the sampling area.





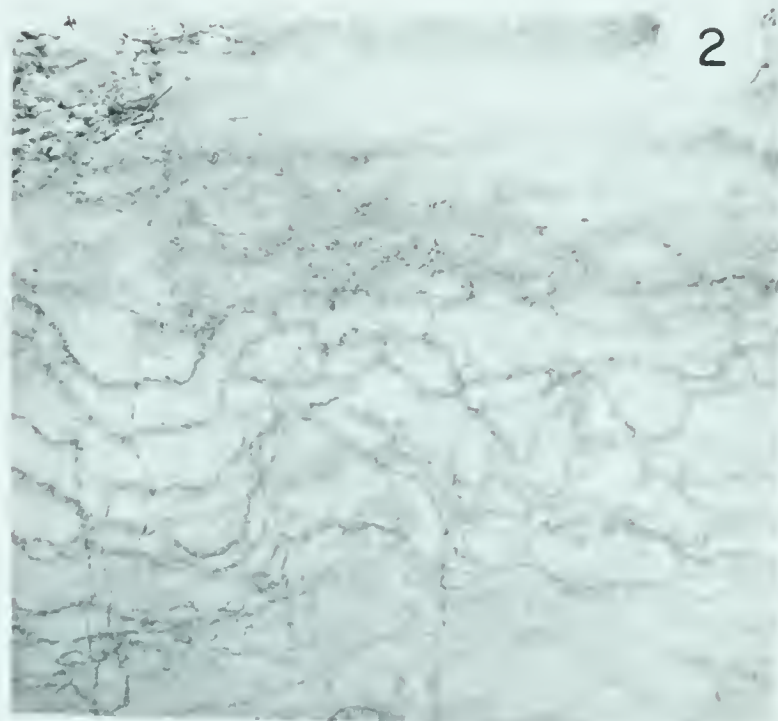


Plate 2. Some photographs of the sampling area at Site 3.



Description of Plate 1

- Picture 1. General appearance of the sampling area at site 1. Note the "Gravelly Contact" about half way down the profile.
- Picture 2. A close up photograph of the profile at site 1 showing parallel bedding which is characteristic of the portion of the profile below the first band in site 1, site 3, and other profiles in the area.
- Picture 3. Photograph showing the "Ae-like" material on the surface at site 1. The bands below this material, and farther down the profile are visible upon close inspection.
- Picture 4. Photograph showing the general appearance of the sampling area at site 2. The thick "Ae-like" material and the bands below are quite apparent. Note the tendency of the bands, especially at the left side of the picture, to migrate toward the surface.
- Picture 5. Photograph of the soil profile at site 2. Note the thinner bands near the surface and thicker ones below.

Description of Plate 2

- Picture 1. Photograph of sampling area at site 3.
- Picture 2. Photograph taken about 0.3 miles away from site 3 showing the fine convolute bands found in some profiles in the area.
- Picture 3. Photograph showing the finer textured material below the Ae at site 3. (The surface has been disturbed as seen at the top of the picture.) Some of the lower bands are apparent while some of the thinner ones are not.





Table I. Profile Description of Site 1

Legal Location SW 29 - 52 - 1 W5

Horizon	Depth (in.)	Color* Dry	Color* Moist	Texture	Structure and Consistency <sup>1</sup>
Ah	0-10	Dark grey 10 YR 4/1	Very dark grey 10 YR 3/1	SL	Weak granular, soft.
	10-14	Light brownish grey 10 YR 6/2	Dark brown 10 YR 3/3	SL	Weak granular, loose to soft.
Ae	14-19	Light brownish grey 10 YR 6/2	Dark brown 10 YR 4/3	SL	Weak granular, loose to soft.
	19-24	Pale brown 10 YR 6/3	Brown 10 YR 5/3	LS	Weak granular, loose to soft.
	24-28	Pale brown 10 YR 6/3	Brown 10 YR 5/3	LS	Weak granular, loose to soft.
(band)	28-30	Light yellowish brown 10 YR 6/4	Brown 7.5 YR 4/4	L	Moderate fine sub-angular blocky, hard.
(inter-band)	30-38	Light yellowish brown 10 YR 6/4	Dark yellowish brown 10 YR 4/4	L	Weak fine sub-angular blocky, slightly hard.
(band)	38-40	Brown 10 YR 5/3	Dark yellowish brown 10 YR 4/4	SL	Moderate fine sub-angular blocky, slightly hard to hard.
(inter-band)	40-44	Pale brown 10 YR 6/3	Brown 10 YR 5/3	LS	Weak fine sub-angular blocky, slightly hard.
(sandy band)	44-51	Pale brown 10 YR 6/3	Dark yellowish brown 10 YR 4/4	S	Amorphous to weak sub-angular blocky, slightly hard.
(band)	51-53	Dark brown 7.5 YR 4/4	Dark brown 7.5 YR 4/4	LS	Amorphous weak sub-angular blocky, slightly hard to hard.

(Continued)



Table I. (Continued)

Horizon	Depth (in.)	Color* Dry	Color* Moist	Texture	Structure and Consistency <sup>1</sup>
(inter-band)	53-58	Very pale brown 10 YR 7/3	Brown 10 YR 5/3	S	Amorphous to single grain soft.
A&B(band)	58-61	Brown 10 YR 5/3	Brown 10 YR 4/3	SL	Amorphous, soft.
(inter-band)	61-66	Pale brown 10 YR 6/3	Yellowish brown 10 YR 5/4	SL	Single grain, soft.
C	66+	Very pale brown 10 YR 7/4	Brown 10 YR 5/3	SiL	Amorphous, slightly hard.
Topography - complex moderately to strongly sloping <sup>1</sup> (5 - 16%). The sample site is at the top of a fairly large knoll.					

\* Munsell colors.

<sup>1</sup> As set forth in the Canadian Classification Scheme.



Table II. Profile Description of Site 2

Legal Location NE 19 - 52 - 1 W5

Horizon	Depth (in.)	Color* Dry	Color* Moist	Texture	Structure and Consistency <sup>1</sup>
Ah	0-10	Very dark grey 10 YR 3/1	Very dark brown 10 YR 2/2	LS	Weak fine granular, soft.
Ahe	10-20	Greyish brown 10 YR 5/2	Very dark grey brown 10 YR 3/2	S	Single grain, loose.
Ae	20-33	Light brownish grey 10 YR 6/2	Brown 10 YR 4/3	S	Single grain, loose.
(band)	33-36	Brown 10 YR 5/3	Brown 7.5 YR 5/4	SL	Weak fine sub-angular blocky, hard.
(interband)	36-39	Pale brown 10 YR 6/3	Yellowish brown 10 YR 5/4	LS	Very weak sub-angular blocky, soft.
(band)	39-40	Brown 10 YR 5/3	Dark brown 7.5 YR 4/4	SL	Moderate blocky, hard.
A&B(interband)	40-42	Pale brown 10 YR 6/3	Yellowish brown 10 YR 5/4	S	Very weak sub-angular blocky, soft.
(band)	42-44	Brown 10 YR 5/3	Brown 7.5 YR 4/4	SL	Moderate blocky, hard.
(interband)	44-56	Pale brown 10 YR 6/3	Pale brown 10 YR 6/3	S	Very weak sub-angular blocky, soft.
(band)	56-61	Brown 10 YR 5/3	Brown 7.5 YR 4/4	SL	Moderate blocky, hard.
(interband)	61-68	Pale brown 10 YR 6/3	Yellowish brown 10 YR 5/4	S	Very weak sub-angular blocky, soft.
(band)	68-69	Brown 10 YR 4/3	Dark brown 10 YR 3/3	S	Very weak sub-angular blocky, soft.
C (interband)	69-82	Light yellowish brown 10 YR 6/4	Brown 10 YR 4/3	S	Single grain, loose.

Topography - The sample site is at the top of a fairly small knoll which is complex, moderately to strongly sloping<sup>1</sup>  
(5 - 16%).

\* Munsell colors  
1 Canadian Soil Classification Scheme





Table III. Profile Description of Site 3

Legal Location SW 15 - 53 - 1 W5

Horizon	Depth (in.)	Color* Dry	Color* Moist	Texture	Structure and Consistency <sup>1</sup>
Ahe	0- 4	Grey brown 10 YR 5/2	Very dark grey brown 10 YR 3/2	L	Weak granular, soft.
Ae	4-10	Light brownish grey 10 YR 6/2	Dark yellowish brown 10 YR 4/4	L	Moderate platy, soft.
(interband)	10-18	Very pale brown 10 YR 7/3	Yellowish brown 10 YR 5/4	SiL	Weak fine sub-angular blocky, hard.
(interband)	18-26 $\frac{1}{2}$	Very pale brown 10 YR 7/3	Yellowish brown 10 YR 5/4	L	Weak fine sub-angular blocky, hard.
(band)	26 $\frac{1}{2}$ -27	Light greyish brown 10 YR 6/2	Pale brown 10 YR 6/3	L	Weak fine sub-angular blocky (platy tendency), hard.
A&B(interband)	27-37	Pale brown 10 YR 6/3	Yellowish brown 10 YR 5/4	SL	Very weak sub-angular blocky, soft.
(thin band)	37-37 $\frac{1}{2}$	Very pale brown 10 YR 7/3	Yellowish brown 10 YR 5/4	SiL	Amorphous, hard.
(band)	37 $\frac{1}{2}$ -43	Very pale brown 10 YR 7/3	Yellowish brown 10 YR 5/4	SiL	Weak fine sub-angular blocky (platy tendency), soft.
(interband)	43-45	Light grey 10 YR 7/2	Yellowish brown 10 YR 5/4	SiL	Very weak sub-angular blocky, soft.
(band)	45-46	Very pale brown 10 YR 7/3	Yellowish brown 10 YR 5/4	SiL	Weak fine sub-angular blocky (platy tendency), soft.
C	46-56	Pale brown 10 YR 6/3	Pale brown 10 YR 6/3	LS	Single grain, loose.

Topography - The sample site is on a small knoll perched halfway up a larger one. The slopes adjacent to the site are complex varying from steeply sloping to moderately sloping<sup>1</sup> (7 - 19%).

\* Munsell colors

<sup>1</sup> Canadian Classification Scheme



However, the band sometimes becomes progressively thinner and closer to the surface from the crown of the knoll toward the steeper slope. The band juts upward a few feet from where it fades out. The bands often appear to become thicker farther down the profile, especially on the steeper, more prominent knolls.

The bands are often quite convolute and sometimes progress vertically, resulting in either abrupt or gradual coalescence. This feature is most prominent in the finer textured soils of the area. In the few cases investigated the convolutions are as erratic in the third dimension as in the plane view. In a few cases doughnut shaped (or tube shaped in three dimensions) areas of band-like materials were noted. These "doughnuts" were 5 - 6 inches in outside diameter and 2 - 3 inches in inside diameter. Bands have been noted to pass upward through or between obviously horizontally bedded material but the bedding did not transect the band. Because the bedding faded out just before reaching the band there may have been a fault in the bedding in which the band developed.

In general the soils of the region have comparatively thick Ah horizons. This horizon is underlain by a material which is morphologically similar to an Ae and about 15 - 35 inches in thickness. Occasionally a thin band is found in the "Ae-like" material, especially when finer textured material occurs below. The bands sometimes migrate into the "Ae-like" material (Figure 4, Plate 1). The depth of this "Ae-like" material seems to be fairly uniform from the top of the slope to the hollows. In the hollows investigated it was found to be of similar depth as on the humps.

The profiles were sampled by horizons, sub-sampling the horizons in a manner which allowed each band and interband region to be sampled separately (Figures 2, 3, and 5). Only those bands of 1/2 of an inch or





greater in thickness were sampled. Sampling was conducted along deep, fresh road cuts and the samples were transferred to plastic bags and taken to the laboratory.

In site 3 the material below the Ae is interband material rather than band material as in the two other profiles. There appears to be some evidence of illuvial clay accumulation but no iron or organic matter accumulation to give the appearance of a band.

Photographs and drawings of the sampling sites and profile descriptions are included in Tables I, II, and III; Plates 1 and 2; and Figures 2 to 5.

## Methods

### A. Preparation of the Sample

The samples were collected and allowed to air dry at room temperature. They were then ground with a porcelain mortar and pestle, passed through a 2 mm. sieve, and were stored in non-sealing screw top containers.

### B. Physical Analysis

Mechanical analyses of the soil samples were determined by the pipette method described by Toogood and Peters (1953). For a detailed analysis 100 grams of sand were separated by wet sieving with a 300 mesh sieve. The sand was then subjected to hydrogen peroxide treatment. Three or more treatments with boiling water for 10 to 15 minutes were used to remove any clay adhering to the sand. The water was removed between treatments by decantation. When the water remained clear upon boiling, the samples were considered to be sufficiently clean. The



total sand was then placed on a nest of 8 inch sieves of appropriate sizes to separate the sands into the various sand fractions. The sieves were then placed on a "ro-tap shaker" for exactly one hour. The sands retained on the various sieves were weighed and the fine sand fraction was further separated for light mineral analysis.

The percentages of various sand fractions are based on total sand while the percentages of sand, silt, and clay are based on oven-dry weight of organic matter and carbonate free soil material.

### C. Chemical Analyses

(a) Soil reaction: pH was determined on a saturated soil paste as outlined by Doughty (1941) using a Beckman Model H2 pH meter equipped with a glass and a calomel electrode.

(b) Nitrogen: Nitrogen was determined by the Kjeldahl-Wilfarth-Gunning method (Association of Official Agricultural Chemists (A.O.A.C.), 1955). A commercially prepared catalyst (Kel-pak<sup>1</sup>), containing HgO (0.41 gm.), CuSO<sub>4</sub> (0.08 gm.), and K<sub>2</sub>SO<sub>4</sub> (9.9 gm.) packaged in a polyethylene bag, was used. The ammonia was collected in a 4 per cent H<sub>3</sub>BO<sub>4</sub> solution as suggested by Meeker and Wagner (1933) and titrated against standardized H<sub>2</sub>SO<sub>4</sub>.

(c) Calcium carbonate equivalent: A modification of the procedure described in A.O.A.C. methods of analysis (1955) was used to determine carbonate carbon. The CO<sub>2</sub> evolved by treating the soil samples with H<sub>2</sub>SO<sub>4</sub> and FeSO<sub>4</sub> was absorbed in ascarite in a Nesbitt bottle. The change in weight of the Nesbitt bottle, representing the CO<sub>2</sub> content is used to calculate the calcium carbonate equivalent.

<sup>1</sup> D-C Tab No. 1, Digestion Catalyst Powders, Harshaw Chemical Co., Cleveland 6, Ohio, U.S.A.





(d) Total carbon: Total carbon was determined using a dry combustion method. The sample is heated in an oxygen atmosphere by an induction furnace. The spent gases are passed through an absorption train to remove all gases except carbon dioxide and oxygen. The sum of the latter two gases is measured volumetrically. The carbon dioxide is then absorbed in a caustic solution and the volume of the carbon dioxide determined by difference. A Leco, model 577-100 carbon analyzer<sup>1</sup> was used for the determinations.

(e) Free iron oxide: Mackenzie's method (1954) was used to determine free iron oxide, with the modification of adding dry  $\text{Na}_2\text{S}_2\text{O}_4$  to the suspension of soil and water. The modification prevents the auto-decomposition of the salt prior to its addition to the soil suspension. The concentration of the iron removed was determined colorimetrically using the o-phenanthroline method outlined by Snell and Snell (1957).

(f) Exchangeable cations and exchange capacity: Exchangeable cations were extracted from the samples with normal ammonium acetate adjusted to pH 7 as outlined in A.O.A.C. methods of analysis (1955). Exchangeable potassium and sodium were determined with the model DU Beckman Flame Spectrophotometer. Exchangeable calcium and magnesium were determined by the Ethylenediaminetetraacetate (E.D.T.A.) method of Cheng and Bray (1951) as outlined in Handbook 60 (1954), except that sodium diethyldithiocarbamate was used to complex iron and aluminum in order to prevent interference.

Exchange acidity was determined by leaching the soil with 0.5 N barium acetate adjusted to pH 7. The leachate was titrated with standardized sodium hydroxide (Brown, 1943).

<sup>1</sup> Laboratory Equipment Corporation, Saint Joseph, Michigan, U.S.A.





The cation exchange capacity was determined by extraction of adsorbed ammonia with normal sodium chloride and distillation of the extract according to the magnesium oxide method for ammoniacal nitrogen determination (A.O.A.C., 1955).

#### D. Mineralogical Analyses

(a) Clay analysis: The separation of clays was carried out by methods used by Pawluk (1961). The clays were dispersed by adjusting the soil suspension to pH 8.0 with sodium hydroxide. The suspension was allowed to equilibrate overnight and then readjusted to pH 8.0. The treatment for the removal of carbonates and soluble salts was found to be unnecessary since they were present only in trace amounts. The separation of the clay and silt was accomplished by repeated decantation of the upper 8 cm. of suspension after standing for 6 hours and 8 minutes as determined from Stoke's Law (Baver, 1959).

The clay fraction was flocculated with magnesium chloride followed by washing with distilled water until a negative test for chlorides was obtained. The concentrated clays were then treated with hydrogen peroxide to remove organic matter. Part of the separated clay was used for the determination of cation exchange capacity. For X-ray analysis the suspensions were mounted on glass slides according to the method of Kittrick (1961). Essentially this entailed taking a few drops of clay suspension, placing it on the slide and allowing the suspension to dry. The glycolation was carried out by placing the prepared air-dried slides in a saturated atmosphere of ethylene glycol. A closed container, in which the slides were placed, was kept in an oven at 60°C. for 48 hours. Dehydration was accomplished by heating the slides to 550°C. for two hours. The slides were stored in a desiccator prior to analysis.



A Norelco X-ray diffractometer equipped with a high angle goniometer,  $\text{CuK}\alpha$  radiation, and a nickel filter was used to identify the clays. The X-ray unit was set at 35 Kilowatts and 15 milliamperes with a scanning time of one degree per minute.

(b) Light mineral analysis: The 0.15 mm. to 0.10 mm. fraction was separated from the fine sand fraction and saved for light mineral separations. The "light" minerals were obtained by flotation on a heavy liquid in a separatory funnel. Separation at a specific gravity of 2.96 was carried out by using tetrabromoethane.

Prior to total fusion analysis of the "light" mineral fraction a microscopic examination was conducted to estimate the quantity of contaminating minerals such as mica that may be present. The amount of contaminating minerals was estimated to be small enough that further separation to a specific gravity of 2.70 was felt unnecessary.

Chemical composition of the light mineral fraction was determined by the hydrofluoric and sulfuric acid method as outlined by Atkinson et al. (1958). Elemental analyses were conducted on the decomposed samples. Sodium and potassium were determined photometrically with the aid of a Beckman Model DU Flame Spectrophotometer. Iron was determined colorimetrically as outlined previously. Sesquioxides were determined gravimetrically according to the method outlined by Kolt Hoff and Sandell (1953). By subtraction of iron from the sesquioxides an estimate of aluminum was obtained. Calcium and magnesium determinations were conducted on the filtrate from the sesquioxide precipitation using the E.D.T.A. method mentioned previously. Silica was determined by the difference between the total weight of original light minerals and the sum of the individual oxides.





## E. Microscopic Analyses

(a) Field sampling: The Uhland core sampler was used for taking cores of the finer textured horizons. The orientation was marked on the retaining cylinder. For some of the coarse textured materials the Uhland core sampler proved to be unsatisfactory. A commercial soup container 2 inches in diameter, cut off to a 2-inch depth in a manner in which a sharp cutting edge was retained was used to sample the very sandy horizons. An undisturbed sample was obtained by trimming the vertical profile surface to the point where damp soil was exposed and pressing the container firmly against the bank with one hand while using a knife to cut around the circumference of the sharp edge of the can. The sample retained in the can was then dried, placed in an impregnation vessel and covered with impregnating material.

(b) Impregnation: The impregnating mixture used was similar to that prepared by Pettapiece (1964). Fifty ml. of Castolite and 50 ml. of styrene were heated at a low temperature and 6 drops of Castolite hardener were added. Heating aided the mixing and lowered the viscosity, thus facilitating impregnation. The styrene lowered the viscosity of the Castolite which also aided in impregnation. More than 6 drops of Castolite hardener caused the casts to crack upon hardening.

The method used for impregnation of the samples was similar to the methods of Buol and Fadness (1961). The oriented, air-dry samples were placed in a vacuum desiccator and evacuated. The impregnation mixture was then introduced under vacuum to cover the sample to about a 1/2-inch depth. The sample was kept evacuated only to the point where bubbles no larger than 1/4 inch in diameter were observed to rise to the surface. Bubbles larger than this disturbed the sample. After 2 to 3



hours the vacuum was released and the sample allowed to cure at room temperature for 3 days. The samples were then placed in the oven and the temperature was raised slowly over 2 to 3 days from 35°C. to 60°C. and finally heated to 75°C. for one hour.

If upon cutting, the soil was found to be insufficiently impregnated, small sections were allowed to dry and were impregnated for a second time according to the above procedure.

(c) Preparation of thin sections: An oil bath diamond saw was used to cut sections of desired orientation and about 3 mm. in thickness trimmed to fit a 27 x 46 mm. glass slide. The most uniform side of the chip was polished as smooth as possible using 400 grit silicon carbide abrasive powder on a lapidary. A glass slide was ground to a predetermined thickness using a glass slide holder<sup>1</sup> on a double diamond glass plate with 600 grit silicon carbide abrasive powder. The slide was then placed on a hot plate at 115°C. to 120°C. with the rough side up. A bar of Lakeside 70 c thermoplastic cement<sup>2</sup> was held on the slide until the required amount had melted off. The slide was left on the hot plate until all the bubbles had disappeared from the cement. The chip, smooth side down, was placed on the slide and moved back and forth until the layer of Lakeside 70 c thermoplastic cement was thin enough that a definite drag was felt. The slide was then removed from the hot plate and placed chip down on a smooth surface with pressure applied until the Lakeside 70 c cooled enough to set. Lateral movement must be avoided during the hardening period. If entrapped bubbles were present, the slide was removed and remounted.

<sup>1</sup> Catalog No. 30-8001AB glass slide holder sold by Buehler Ltd., Metallurgical Apparatus, 2120 Greenwood Street, Evanston, Illinois, U.S.A.

<sup>2</sup> Hugh Courtright and Co., 7652 Vincennes Avenue, Chicago 20, Illinois, U.S.A.





The chip was ground with 240 grit silicon carbide abrasive powder and varsol on a lapidary to remove the bulk of the material. A thin section slide holder<sup>1</sup> was used to hold the slide and chip. Grinding was continued until a thickness of about 0.5 mm. was obtained. After thorough cleaning with varsol the slide was ground to a thickness of about 0.1 to 0.08 mm. using 400 grit silicon carbide abrasive powder. The section was again carefully washed to remove all coarse grinding compound. Final grinding was done by hand, on a double diamond glass plate using 600 grit silicon carbide grinding powder. The slide was held with the fingers for this procedure because the weight of the thin section slide holder resulted in plucking of the larger grains. Frequent checks were made until the sample was from 0.06 to 0.04 mm. in thickness as determined from interference colors.

Cover slips were mounted on the dry thin sections using Cadex<sup>2</sup>. A small drop of Cadex was placed centrally on the cold thin section and a cover slip was placed gently on top. The whole assembly was placed on the hot plate, preheated to about 65°C., until the Cadex had reached all corners of the cover slip. The cover slip was then pressed gently to force any bubbles to the edge and to be sure that the mounting medium was thin. The excess mounting medium was removed with xylene. The prepared thin section was now ready for petrographic investigations.

<sup>1</sup> Catalog No. 30-8000AB slide holder, sold by Buehler Ltd., Metallurgical Apparatus, 2120 Greenwood Street, Evanston, Illinois U.S.A.

<sup>2</sup> Wards Natural Science Establishment, Inc., Rochester, N.Y., U.S.A.





#### IV. RESULTS AND DISCUSSION

Physical, chemical, mineralogical, and micropedological analyses were conducted on soil samples from the pitted deltaic materials west of Edmonton to determine the origin of the bands present in the profiles (Tables IV to XVI).

Mechanical analysis data were used to construct cumulative curves and particle size frequency distribution curves in order to determine whether the bands are pedogenic or geologic by assessing the degree of stratification within the profile. Particle size frequency distribution curves and cumulative curves are also useful in determining the mode of deposition of the materials from which the soils are formed.

Chemical analyses serve to characterize the soils under study and assist in determining the presence and degree of pedogenic activity in the formation of the bands. For example, accumulation of materials such as free iron oxide and organic matter in the bands provide evidence for illuviation.

Mineralogical analyses such as clay mineral identification reveal some of the genetic characteristics of the soil profile. Light and heavy mineral separations assist in recognizing mineralogical stratification in the soil profiles. Elemental analyses especially on the light mineral fraction assist in the estimation of the amount of weathering in the profiles.

Micropedological investigations are used to indicate whether the bands are characterized by clay accumulations, iron accumulations, and/or organic matter and to suggest whether the clay is illuvial in origin. Textural variations are also evident in thin section examinations with the Petrographic microscope.



Table IV. Mechanical Analysis of the Soils at Site 1

Sample No.	Horizon	Depth (in.)	Sand Fractions*							Sand %	Silt %	Clay %
			v.c.s. %	c.s. %	m.s. %	f.s. %	v.f.s. %	f.s. v.f.s.				
1	Ah	0-10	T**	T	4	36	60	0.60	70	23	7	
2		10-14	T	T	4	46	50	0.92	71	21	8	
3	Ae	14-19	T	T	4	53	43	1.23	74	19	7	
4		19-24	T	T	3	48	48	1.00	83	12	5	
5		24-28	T	T	3	76	21	3.62	86	9	5	
6	(band)	28-30	T	T	2	41	57	0.72	47	31	22	
7	(interband)	30-38	T	T	2	24	73	0.33	41	42	17	
8	(band)	38-40	4	5	20	52	19	2.74	66	20	14	
9	(interband)	40-44	T	T	7	82	10	8.20	84	8	8	
10	A&B(sandy band)	44-51	T	T	8	86	6	14.33	89	6	5	
11	(band)	51-53	T	T	7	86	7	12.29	85	3	12	
12	(interband)	53-58	0	T	5	90	5	18.00	91	5	4	
13	(band)	58-61	0	0	1	84	15	5.60	72	14	14	
14	(interband)	61-66	0	T	T	78	21	3.71	67	19	14	
15	C	66+	T	T	3	39	58	0.67	12	65	23	

\* Based on Summation of Sand Fraction  
\*\* Less than 1 per cent





Table V. Mechanical Analysis of the Soils at Site 2

Sample No.	Horizon	Depth (in.)	Sand Fractions*						Sand %	Silt %	Clay %
			v.c.s. %	c.s. %	m.s. %	f.s. %	v.f.s. %	f.s. v.f.s.			
16	Ah	0-10	T**	T	3	87	10	8.70	86	8	6
17	Ahe	10-20	T	T	3	79	18	4.39	88	7	5
18	Ae	20-33	0	T	3	83	14	5.93	90	6	4
19	↑ (band) (interband) (band) ↓	33-36	T	T	2	90	8	11.25	74	7	19
20		36-39	0	T	4	73	22	3.32	86	T	14
21		39-40	0	T	4	80	17	4.71	78	6	16
22	A&B (interband)	40-42	0	T	4	88	9	9.78	89	4	7
23	(band) (interband) (band)	42-44	0	T	4	85	12	7.08	78	6	16
24		44-56	T	T	5	84	11	7.64	92	4	4
25		56-61	0	T	4	68	28	2.43	82	4	14
26	(interband)	61-68	0	T	6	77	17	4.53	93	3	4
27	(band)	68-69	0	T	2	54	44	1.23	89	3	8
28	C (interband)	69-82	T	T	6	80	14	5.71	92	2	6

\* Based on Summation of Sand Fraction

\*\* Less than 1 per cent



Table VI. Mechanical Analysis of the Soils at Site 3

Sample No.	Horizon	Depth (in.)	Sand Fractions*							Sand %	Silt %	Clay %
			v.c.s. %	c.s. %	m.s. %	f.s. %	v.f.s. %	$\frac{\text{f.s.}}{\text{v.f.s.}}$				
29	Ahe	0- 4	T**	T	T	40	60	0.67	48	40	12	
30	Ae	4-10	T	T	1	44	55	0.80	46	42	12	
31	↑ (interband)	10-18	0	T	T	18	82	0.22	24	56	20	
32		(interband)	18-26½	0	T	T	28	72	0.39	43	41	16
33		(band)	26½-27	0	T	T	26	74	0.35	50	32	18
34	A&B (interband)	27-37	0	0	T	41	59	0.69	60	28	12	
35	↓ (thin band)	37-37½	0	T	1	25	74	0.34	4	68	28	
36		(band)	37½-43	0	T	T	6	93	0.06	4	63	33
37		(interband)	43-45	0	T	T	20	80	0.25	24	61	15
38	(band)	45-46	0	T	T	25	75	0.33	10	68	22	
39		C	46-56	0	0	T	75	25	3.00	81	16	3

\* Based on Summation of Sand Fraction

\*\* Less than 1 per cent



Table VII. Some Chemical Analyses of the Soils at Site 1

Sample No.	Horizon	Depth (in.)	% of Total Exchangeable Cations					Total C.E.C. me./100 g.		CaCO <sub>3</sub> %	Total Carbon %	N %	Free Fe <sub>2</sub> O <sub>3</sub> %	
			H <sup>++</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>	Sum of Ex.Cat.	Deter-mined				pH	
1	Ah	0-10	14.2	72.9	11.6	--	1.3	15.5	14.1	ND**	1.89	0.13	5.5	0.82
2		10-14	15.1	67.4	14.0	--	3.5	8.6	7.5	ND	0.48	0.05	5.6	0.83
3	Ae	14-19	13.7	68.0	16.4	1.3	1.4	7.3	6.3	ND	0.34	0.04	5.7	0.73
4		19-24	13.7	67.1	15.7	--	3.9	5.1	4.6	ND	0.17	0.02	5.9	0.61
5		24-28	13.0	68.5	16.7	--	1.9	5.4	4.3	ND	0.07	0.02	5.9	0.63
6	(band)	28-30	8.5	70.6	19.8	0.6	0.6	17.7	16.5	ND	0.27	0.04	5.5	1.57
7	(interband)	30-38	8.8	74.8	13.6	0.7	2.0	14.7	13.5	ND	0.26	0.03	5.6	1.50
8	(band)	38-40	11.5	71.5	13.8	0.8	2.3	13.0	12.5	ND	0.29	0.03	5.7	1.45
9	(interband)	40-44	8.3	70.2	20.2	--	1.2	8.4	7.8	ND	0.13	0.02	6.0	0.86
10	A&B (sandy band)	44-51	8.5	66.1	22.0	1.7	1.7	5.9	5.1	ND	0.04	0.01	6.2	0.77
11	(band)	51-53	9.0	67.0	21.0	1.0	2.0	10.0	9.1	ND	0.25	0.02	5.9	1.13
12	(interband)	53-58	9.1	69.1	16.4	1.8	3.6	5.5	5.1	ND	0.05	0.01	6.2	0.69
13	(band)	58-61	9.3	67.1	20.0	1.4	2.1	14.0	13.0	0.01	0.03	0.03	5.6	1.33
14	(interband)	61-66	9.2	65.5	23.5	0.8	0.8	11.9	10.7	0.04	0.32	0.02	5.6	1.26
15	C	66+	8.1	66.2	23.3	0.5	1.9	21.0	20.4	0.04	0.47	0.04	5.6	2.29

\* Exchange acidity  
 \*\* ND -- Not Determined





Table VIII. Some Chemical Analyses of the Soils at Site 2

Sample No.	Horizon	Depth (in.)	% of Total Exchangeable Cations					Total C.E.C. me./100 g.		CaCO <sub>3</sub> %	Total Carbon %	N %	pH	Free Fe <sub>2</sub> O <sub>3</sub> %
			H <sup>+</sup>	Ca	Mg	Na	K	Sum of Ex.Cat...	Deter-mined					
16	Ah	0-10	20.1	65.3	12.1	--	2.4	12.4	11.0	ND**	1.52	0.13	5.5	0.64
17	Ahe	10-20	11.3	71.0	16.1	--	1.6	6.2	6.0	ND	0.54	0.05	5.7	0.63
18	Ae	20-33	16.7	64.6	16.7	--	2.1	4.8	4.0	ND	0.23	0.02	5.9	0.54
19	(band)	33-36	15.3	66.2	15.9	0.6	1.9	15.7	14.6	ND	0.45	0.04	5.2	1.36
20	(interband)	36-39	14.8	63.0	19.8	1.2	1.2	8.1	7.2	ND	0.22	0.02	5.7	0.74
21	(band)	39-40	12.9	65.5	20.1	0.7	0.7	13.9	13.1	ND	0.30	0.03	5.3	1.24
22	A&B (interband)	40-42	16.1	59.7	22.6	1.6	0.6	6.2	5.5	ND	0.17	0.02	5.7	0.72
23	(band)	42-44	11.9	66.4	20.3	0.7	0.7	14.3	13.4	ND	0.32	0.03	5.4	1.33
24	(interband)	44-56	14.8	61.1	20.4	1.9	1.9	5.4	4.8	ND	0.17	0.01	5.9	0.70
25	(band)	56-61	11.8	62.2	22.0	1.6	2.4	12.7	11.6	ND	0.30	0.03	5.3	1.16
26	(interband)	61-68	10.9	60.0	25.5	1.8	1.8	5.5	4.5	ND	0.16	0.01	5.9	0.63
27	(band)	68-69	14.0	64.5	19.6	0.9	0.9	10.7	9.5	0.05	0.59	0.03	5.8	0.88
28	(interband)	69-82	10.1	59.4	27.5	1.4	1.4	6.9	5.5	--	0.14	0.01	5.8	0.70

\* Exchange acidity

\*\* ND -- Not Determined



Table IX. Some Chemical Analyses of the Soils at Site 3

Sample No.	Horizon	Depth (in.)	% of Total Exchangeable Cations				Total C.E.C. me./100 g.		CaCO <sub>3</sub> %	Total Carbon %	N %	pH	Free Fe <sub>2</sub> O <sub>3</sub> %
			H <sup>+</sup> *	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>	Sum of Ex.Cat. Deter-mined					
29	Ahe	0- 4	7.6	80.3	11.6	--	0.5	19.8	18.7	2.34	0.17	6.4	1.07
30	Ae	4-10	8.1	73.0	16.2	--	2.7	11.1	10.3	0.44	0.05	6.3	1.18
31	(interband)	10-18	3.8	81.7	14.0	--	0.5	18.6	18.1	0.39	0.05	6.5	1.85
32		18-26½	5.2	72.9	21.9	--	--	15.5	16.4	0.29	0.04	6.1	1.66
33		26½-27	4.6	70.7	24.1	--	0.6	17.4	16.9	0.19	0.02	5.8	2.01
34	A&B	27-37	7.2	68.0	23.7	--	1.0	9.7	10.0	0.15	0.02	6.1	1.33
35	(thin band)	37-37½	7.1	66.2	26.0	--	0.6	15.4	15.1	0.53	0.05	6.0	2.78
36		37½-43	5.3	67.6	25.8	0.4	0.8	24.4	22.5	0.51	0.05	6.0	2.87
37		43-45	6.5	65.5	26.8	0.6	0.6	16.8	15.1	0.40	0.03	6.0	2.11
38	(band)	45-46	5.8	66.7	26.6	0.5	0.5	20.7	18.5	0.50	0.05	5.8	2.97
39	C	46-56	6.9	63.8	25.9	1.7	1.7	5.8	5.0	0.07	0.01	6.4	1.06

\* Exchange acidity  
 \*\* ND -- Not Determined





Table X. Clay Mineral Distribution in the Profile at Site 1

Sample No.	Horizon	Montmorillonite*	Illite*	Kao-linite*	Chlorite*	Quartz*	C.E.C.**	Remarks
1	Ah	5	3	3	2	3	47.2	Broad montmorillonite peak (glycolated).
2	↑	5	3	3	2	3	43.0	Indications of an 11.5 Å <sup>0</sup> peak.
3	Ae	5	3	3	2	3	42.8	Possibly a trace of interstratified clay minerals (as in sample 2).
4		5	3	3	2	3	38.0	Less interstratification than sample 3.
5		5	3	3	2	3	42.9	Less interstratification than sample 4.
6	(band)	5	2	2	1	2	58.0	Sharper, better defined montmorillonite peak.
7	(interband)	5	2	2	1	2	56.9	Less montmorillonite than sample 6.
8	(band)	5	2	2	1	2	57.5	Similar to sample 7.
9	(interband)	5	2	2	1	2	62.2	Broad 10 Å <sup>0</sup> peak (heated and glycolated).
10	A&B (sandy band)	5	2	2	2	2	58.5	Less montmorillonite than sample 9, some chlorite.
11	(band)	5	2	2	1	2	57.8	Similar to sample 10, no chlorite.
12	(interband)	5	2	2	1	2	59.8	More montmorillonite than sample 11.
13	(band)	5	2	2	1	2	60.8	Weathered illite or interstratified.
14	(interband)	5	2	2	1	2	57.3	Good glycolated illite peak.
15	C	5	2	2	1	2	56.7	Little more montmorillonite than sample 14.

\* Expressed as relative quantities in the following serial progression:

1. None; 2. Trace 0-10%; 3. Minor 10-35%; 4. Major 35-60%; 5. Dominant 60-100%.

\*\* Me. per 100 gm.



Table XI. Clay Mineral Distribution in the Profile at Site 2

Sample No.	Horizon	Montmor- illonite*	Illite*	Kao- linite*	Chlorite*	Quartz*	C.E.C.**	Remarks
16	Ah	5	2	3	1	3	46.7	Similar in appearance to sample 1.
17	Ahe	4	3	3	2	3	42.6	Similar to samples 2 to 5.
18	Ae	4	3	3	2	3	36.4	Little less montmorillonite than sample 17, otherwise same.
19	(band)	5	2	2	1	2	46.7	Similar to samples 6 to 15.
20	(interband)	5	2	2	1	2	54.6	Similar to sample 19.
21	(band)	5	2	2	1	2	58.8	More montmorillonite than samples 19 and 20.
22	A&B (interband)	5	2-3	2-3	1	2-3	52.8	Less montmorillonite than sample 21.
23	(band)	5	2	2	1	2	64.4	More montmorillonite than sample 22 but less than sample 21.
24	(interband)	5	2	2	1	2	59.4	Similar to sample 23.
25	(band)	5	2	2	1	2	68.7	Little more montmorillonite than sample 24.
26	(interband)	5	2	2-3	1	2	58.0	Similar to sample 23 but a little more kaolinite and illite.
27	(band)	5	2	2	1	2	61.7	Similar to sample 25, little less montmorillonite.
28	C (interband)	5	2	2	1	2	66.1	Similar to sample 27.

\* Expressed as relative quantities in the following serial progression:

1. None
2. Trace
3. Minor 10-35%
4. Major 35-60%
5. Dominant 60-100%

\*\* Me. per 100 gm.



Table XII. Clay Mineral Distribution in the Profile at Site 3

Sample No.	Horizon	Montmor- illonite*	Illite*	Kao- linite*	Chlorite*	Quartz*	C.E.C.**	Remarks
29	Ahe	5	2	3	1	3	47.4	Similar to sample 1, no chlorite.
30	Ae	4-5	3	3	1	3	47.5	Similar to samples 2-5 and samples 17 and 18.
31	(interband)	5	2	2	1	2	61.6	Similar to samples 6-13 and samples 19-28.
32	(interband)	5	2	2	1	2	66.6	Similar to sample 31 except very high in montmorillonite and very little illite.
33	(band)	5	2	2	1	2	68.5	Similar to sample 32.
34	A&B (interband)	5	2	2	1	2	60.4	Similar to sample 33, little less montmorillonite.
35	(thin band)	5	2	2	1	2	53.7	Similar to sample 34.
36	(band)	5	2	2	1	2	50.7	Similar to sample 34.
37	(interband)	5	2	2	1	2	52.4	Similar to sample 36, less montmorillonite.
38	(band)	5	2	2	1	2	49.9	Similar to sample 37, less montmor- illonite, more kaolinite and illite.
39	C	5	2	2	1	2	62.8	Similar to sample 34.

\* Expressed as relative quantities in the following serial progression:

1. None
2. Trace 0-10%
3. Minor 10-35%
4. Major 35-60%
5. Dominant 60-100%

\*\* Me. per 100 gm.





Table XIII. Percentage Composition of Light (sp. gr. <2.96) and Heavy (sp. gr. >2.96) Minerals in the 0.10 - 0.15 mm. Sand Fraction

Sample No.	Horizon	Depth (in.)	% <2.96	% >2.96	$\frac{<2.96}{>2.96}$
<u>Site 1</u>					
1	Ah	0-10	99	0.8	120
2	↑	10-14	99	0.6	170
3	Ae	14-19	99	0.4	250
4	↓	19-24	99	0.5	200
5	↓	24-28	99	0.6	170
6	↑ (band)	28-30	99	0.6	170
7	(interband)	30-38	99	0.6	170
8	(band)	38-40	95	4.7	20
9	(interband)	40-44	99	1.2	80
10	A&B (sandy band)	44-51	98	1.4	80
11	(band)	51-53	98	2.1	50
12	(interband)	53-58	98	1.5	70
13	(band)	58-61	99	0.8	120
14	↓ (interband)	61-66	99	0.4	250
15	C	66+	99	0.6	170
<u>Site 2</u>					
16	Ah	0-10	99	0.6	170
17	Ahe	10-20	99	0.6	170
18	Ae	20-33	99	0.7	140
19	↑ (band)	33-36	99	0.7	140
20	(interband)	36-39	99	0.6	170
21	(band)	39-40	99	0.7	140
22	A&B (interband)	40-42	99	0.8	120
23	(band)	42-44	99	0.8	120
24	(interband)	44-56	99	0.8	120
25	(band)	56-61	99	0.7	140
26	(interband)	61-68	99	0.8	120
27	↓ (band)	68-69	100	0.5	200
28	C (interband)	69-82	99	0.9	110
<u>Site 3</u>					
29	Ahe	0- 4	99	0.5	200
30	Ae	4-10	99	0.7	140
31	↑ (interband)	10-18	99	0.5	200
32	(interband)	18-26 $\frac{1}{2}$	100	0.5	200
33	(band)	26 $\frac{1}{2}$ -27	100	0.4	250
34	A&B (interband)	27-37	99	0.6	170
35	(thin band)	37-37 $\frac{1}{2}$	99	0.4	250
36	(band)	37 $\frac{1}{2}$ -43	99	0.5	200
37	(interband)	43-45	99	0.5	200
38	↓ (band)	45-46	99	0.6	170
39	C	46-56	99	1.2	80



Table XIV. Elemental Analysis of Light Minerals\* (Sp. Gr. <2.96) in the Profile at Site 1

Sample No.	Horizon	Depth (in.)	% Fe <sub>2</sub> O <sub>3</sub>	% Al <sub>2</sub> O <sub>3</sub>	% CaO	% MgO	% Na <sub>2</sub> O	% K <sub>2</sub> O	% SiO <sub>2</sub>	SiO <sub>2</sub> / Al <sub>2</sub> O <sub>3</sub>
1	Ah	0-10	0.47	5.88	1.08	0.64	1.25	1.01	89.67	15.3
2		10-14	0.45	5.80	1.18	0.59	0.37	0.50	91.11	15.7
3	Ae	14-19	0.47	5.93	1.03	0.60	0.51	0.48	90.98	15.3
4		19-24	0.48	6.34	1.09	0.54	1.20	1.00	89.35	14.1
5		24-28	0.49	6.11	0.87	0.74	1.02	0.98	89.79	14.7
6	(band)	28-30	0.49	6.07	1.27	0.43	1.05	1.00	89.69	14.8
7	(interband)	30-38	0.51	6.17	1.15	0.66	1.38	1.42	88.71	14.4
8	(band)	38-40	0.77	6.38	0.88	0.86	0.52	0.42	90.17	14.1
9	(interband)	40-44	0.69	6.53	1.32	0.78	0.96	0.86	88.86	13.6
10	A&B (sandy band)	44-51	0.68	6.23	1.13	0.75	1.04	0.90	89.27	14.3
11	(band)	51-53	0.45	6.01	1.12	0.81	0.88	0.60	90.13	15.0
12	(interband)	53-58	0.50	6.08	1.18	0.62	1.13	0.80	89.67	14.7
13	(band)	58-61	0.71	6.74	1.07	0.78	0.97	0.82	88.91	13.2
14	(interband)	61-66	0.76	7.16	1.44	0.75	1.31	1.06	87.76	12.3
15	C	66+	0.92	7.46	1.15	1.11	1.22	0.96	87.18	11.7

\* Average values of duplicate determinations





Table XV. Elemental Analysis of Light Minerals\* (Sp. Gr. <2.96) in the Profile at Site 2

Sample No.	Horizon	Depth (in.)	% Fe <sub>2</sub> O <sub>3</sub>	% Al <sub>2</sub> O <sub>3</sub>	% CaO	% MgO	% Na <sub>2</sub> O	% K <sub>2</sub> O	% SiO <sub>2</sub>	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$
16	Ah	0-10	0.46	6.18	0.95	0.52	1.20	0.92	89.77	14.5
17	Ahe	10-20	0.51	6.19	1.27	0.46	0.82	0.66	90.09	14.6
18	Ae	20-33	0.54	6.54	1.38	0.57	1.07	0.90	89.00	13.6
19	(band)	33-36	0.55	6.65	1.15	0.69	1.18	1.08	88.70	13.3
20	(interband)	36-39	0.54	6.54	1.17	0.62	1.13	1.04	88.96	13.6
21	(band)	39-40	0.52	6.51	1.50	0.74	1.04	0.58	89.11	13.7
22	A&B (interband)	40-42	0.55	6.53	1.17	0.67	1.22	0.80	89.06	13.6
23	(band)	42-44	0.55	6.54	1.22	0.63	1.11	0.68	89.27	13.6
24	(interband)	44-56	0.60	6.73	0.98	0.78	0.67	0.48	89.76	13.3
25	(band)	56-61	0.55	6.25	1.22	0.84	1.34	1.00	88.80	14.2
26	(interband)	61-68	0.57	6.30	1.36	0.73	1.36	1.00	88.68	14.1
27	(band)	68-69	0.72	6.11	1.44	0.67	1.31	1.06	88.69	14.5
28	C (interband)	69-82	0.61	6.42	1.37	0.59	1.25	0.98	88.78	13.8

\* Average values of duplicate determinations



Table XVI. Elemental Analysis of Light Minerals\* (Sp. Gr. <2.96) in the Profile at Site 3

Sample No.	Horizon	Depth (in.)	% Fe <sub>2</sub> O <sub>3</sub>	% Al <sub>2</sub> O <sub>3</sub>	% CaO	% MgO	% Na <sub>2</sub> O	% K <sub>2</sub> O	% SiO <sub>2</sub>	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$
29	Ahe	0- 4	0.60	6.41	1.48	0.54	1.19	0.96	88.82	13.9
30	Ae	4-10	0.76	6.98	1.40	0.74	1.24	0.98	87.90	12.6
31	(interband)	10-18	0.61	6.83	1.17	0.62	0.84	0.68	89.25	13.1
32	(interband)	18-26 $\frac{1}{2}$	0.81	7.63	1.11	0.83	0.82	0.72	88.08	11.5
33	(band)	26 $\frac{1}{2}$ -27	0.68	7.20	1.49	0.68	1.25	0.94	87.76	12.2
34	A&B (interband)	27-37	0.80	7.23	1.45	0.76	1.43	1.02	87.31	12.1
35	(thin band)	37-37 $\frac{1}{2}$	0.74	6.84	1.53	0.76	0.93	0.80	88.40	12.9
36	(band)	37 $\frac{1}{2}$ -43	2.06	8.79	1.48	2.13	1.18	0.92	83.44	9.5
37	(interband)	43-45	1.10	7.76	1.33	1.29	1.21	1.02	86.29	11.1
38	(band)	45-46	1.03	7.65	1.42	0.98	1.22	0.98	86.72	11.3
39	C	46-56	0.70	6.26	1.46	0.70	1.23	0.90	88.75	14.2

\* Average values of duplicate determinations



### Physical Analysis

Mechanical Analysis: Mechanical analysis provides the percentage distribution of particle sizes in a soil sample (Baver, 1959). The size separations are those used in the Canadian Classification Scheme and are reported in Tables IV, V, and VI.

The three profiles studied were relatively coarse in texture.

The profile at site 1 (Table IV) is quite variable in particle size distribution throughout the solum. In general the samples are loamy sand to sandy loam in texture. The fine textured silt loam in the lowest horizon is considered indicative of a stratified deposit.

The profile at site 2 (Table V) is less variable than the profile at site 1 or site 3, having sandy loam to sand textures throughout.

Loam and silt loam textures are the most prominent in the profile at site 3 (Table VI) although the lowest horizon is loamy sand, which is considered further evidence of stratification.

In general the band materials contain more clay than the interband materials. This is especially evident at site 2 where the accumulation of clay in the band is greater than two per cent more than the interband. Although the clay accumulation is sufficient to meet one of the requirements for a Bt horizon as defined by the Canadian Classification Scheme the fact that it is less than one-tenth as thick as the overlying horizons and less than six inches in total thickness does not permit its designation as a Bt horizon.

A gravelly contact is evident at site 1 and generally occurs immediately below the "Ae-like" surface material. With this exception all three profiles have negligible amounts of very coarse sand and coarse sand present. Medium sand is generally absent in the profile at site 3 and





occurs only in small quantities in the profiles at site 1 and site 2.

Variations in quantity of sand and coarse silt fractions are evident at different depths (Tables IV, V, and VI) which suggest that the materials in the profile are to some extent stratified since these size fractions are considered non-mobile. Ratios of fine sand to very fine sand (Tables IV to VI), particle size frequency distribution curves (Figures 6 to 8), and cumulative curves (Figures 9 to 17) also indicate that there is considerable stratification in site 1 and site 3. Stratification to a lesser degree is also evident in site 2. In the sites sampled the bands tend to coincide with stratification changes, although the bands do not always occupy the entire strata in which they occur. In the profile at site 1 the top band is associated with a stratification change. The top band in the profile at site 3 does not coincide with any obvious stratification, although cumulative curves suggest some stratification may exist.

The particle size frequency distribution curves are based on the particle size distribution of the total sample. Therefore, in an eluvial region the per cent sand may be increased by negative enrichment, in spite of uniform deposition. Thus, the height of the peaks at the most abundant size fraction may be increased. Taking this variable into consideration the particle size frequency distribution curves clearly show stratification.

The particle size frequency distribution curves show that a definite concentration of particles occurs around the 0.1 mm. size fraction in site 1 and site 2. A concentration of particles in the silt range is evident in site 3. Since no determinations were made to subdivide the silt region, the size fraction of greatest concentration in site 3 is not known accurately.



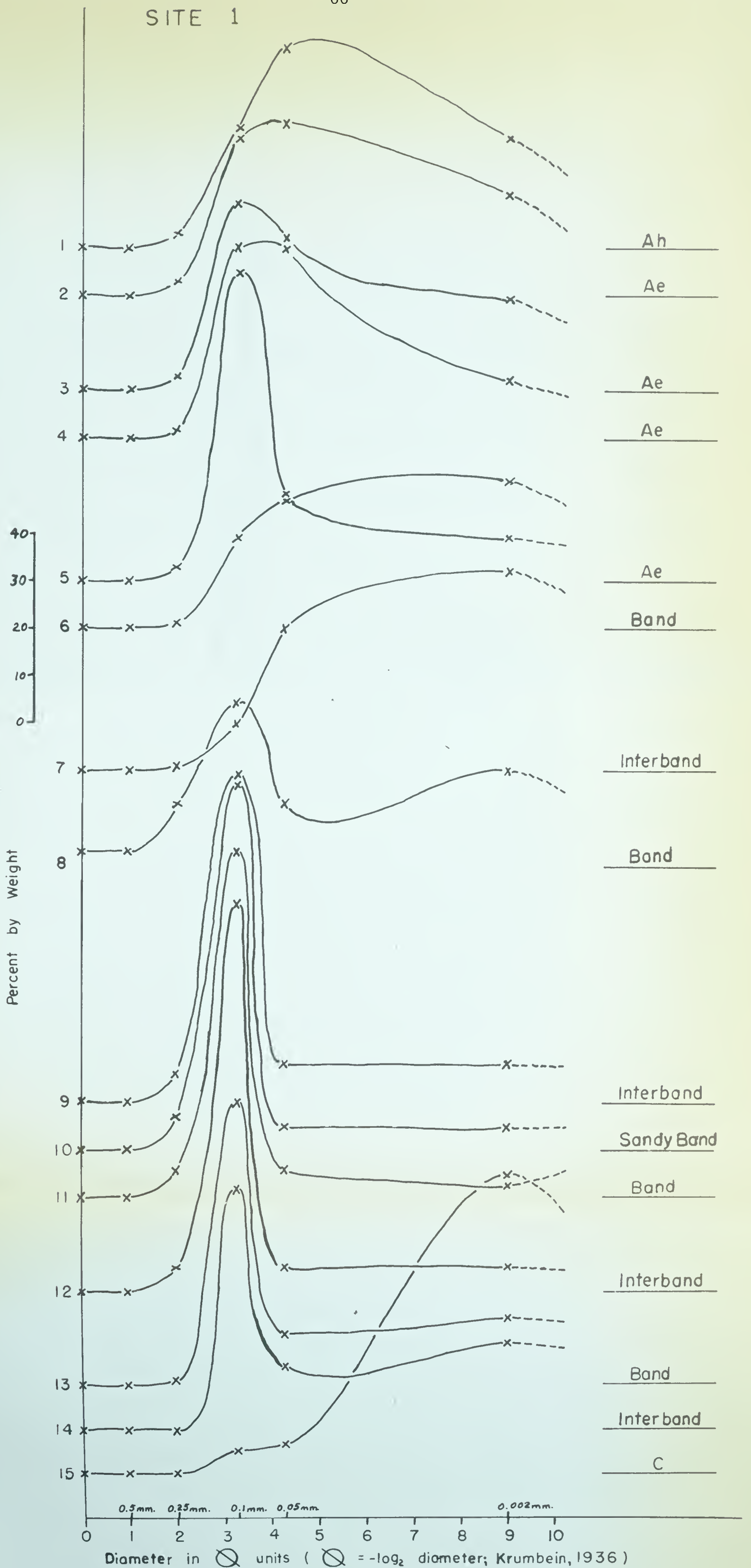


Figure 6 - Particle size frequency distribution curves. The plots represent the percent by weight retained on a given sieve.





SITE 2

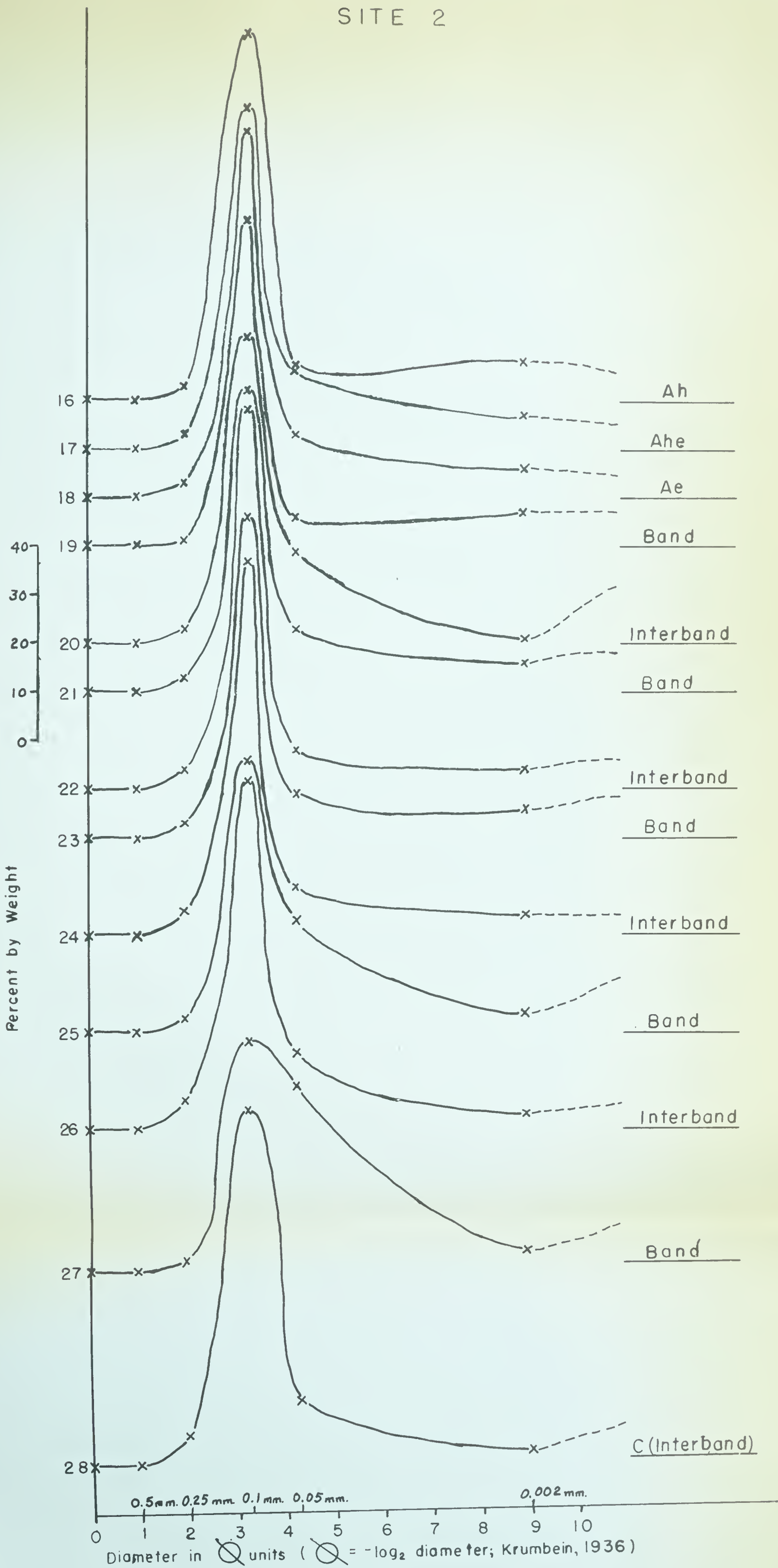


Figure 7 - Particle size frequency distribution curves. The plots represent the percent by weight retained on a given sieve.



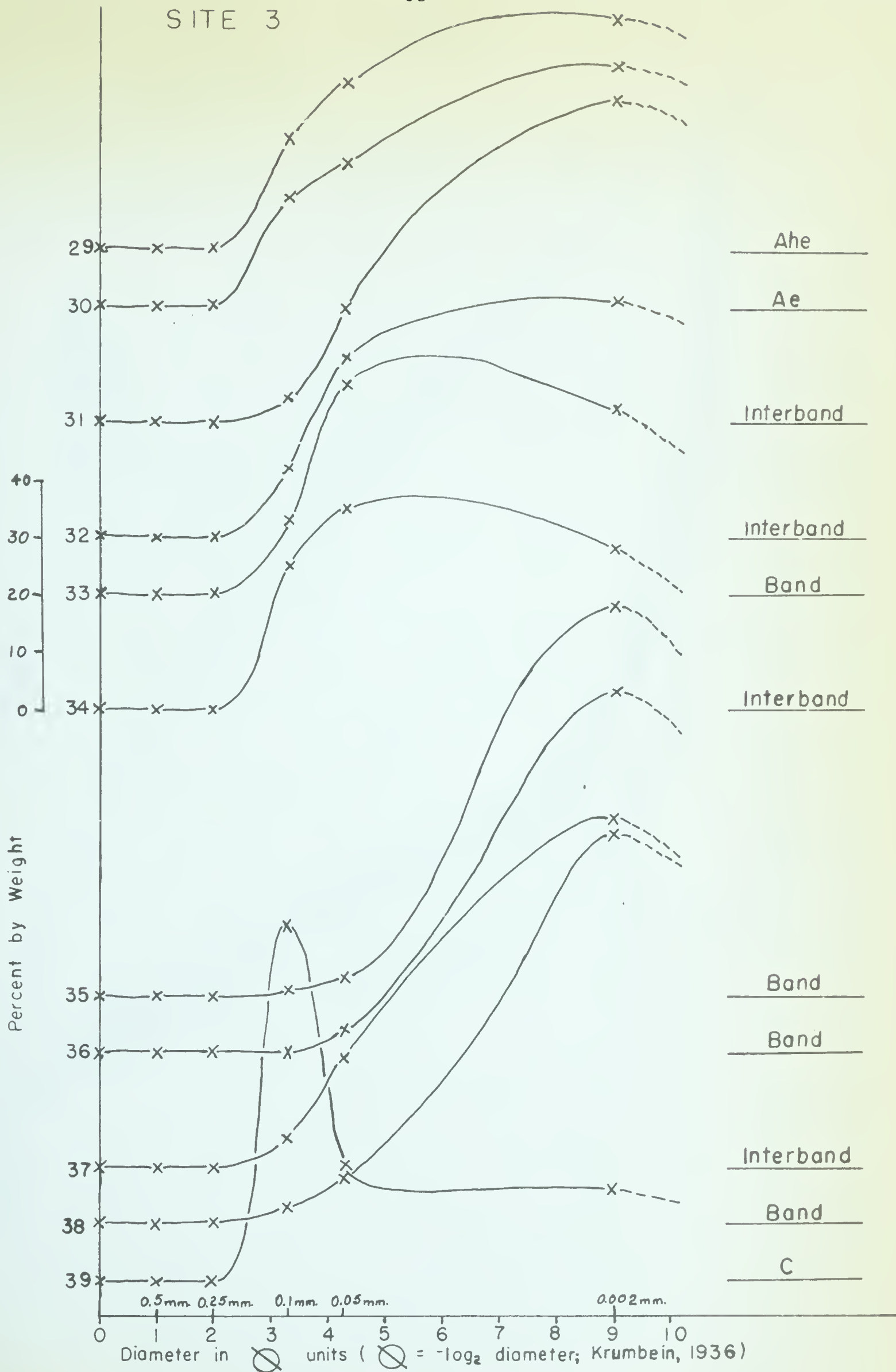


Figure 8 - Particle size frequency distribution curves. The plots represent the percent by weight retained on a given sieve.



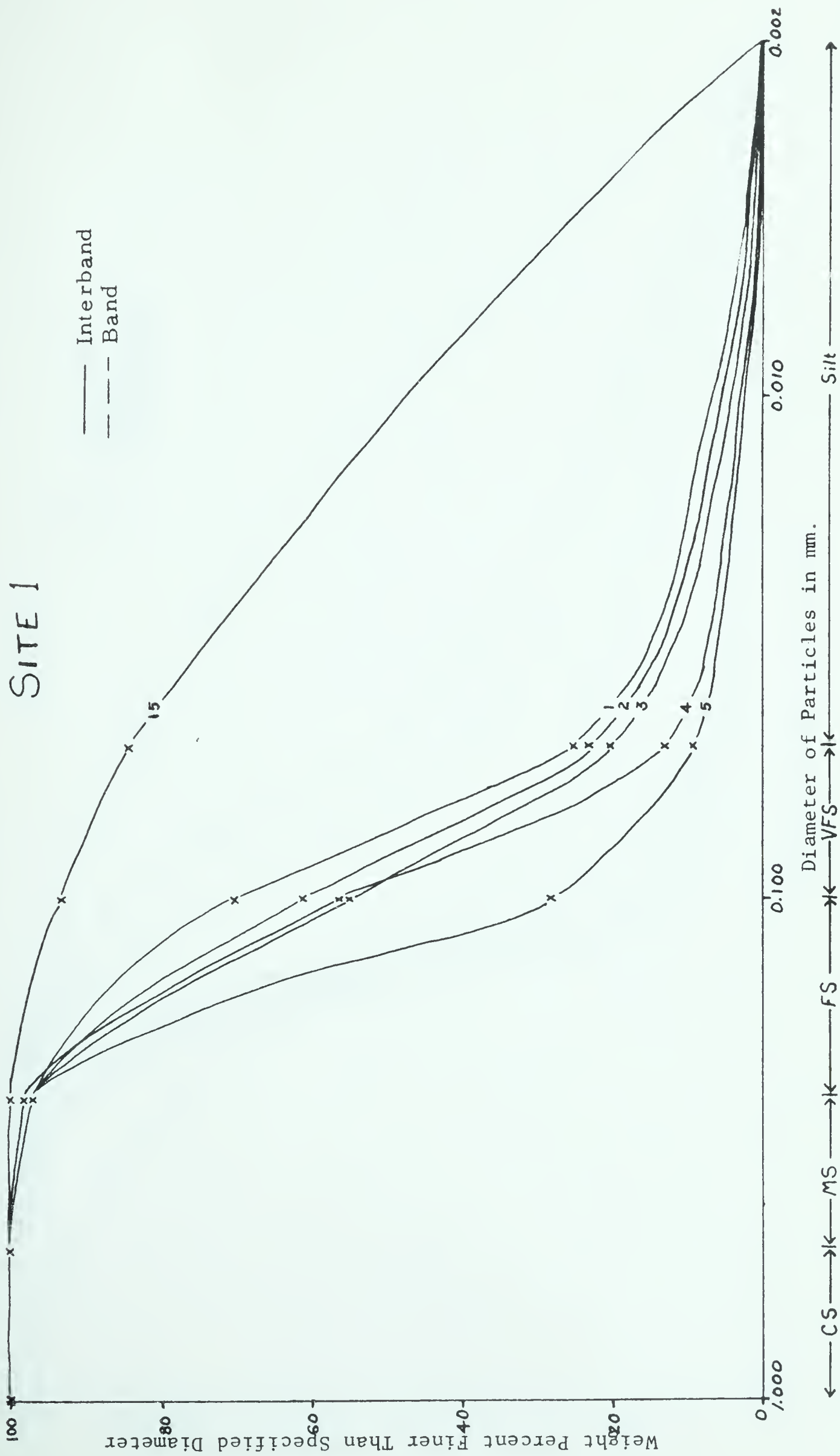


Figure 9 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).





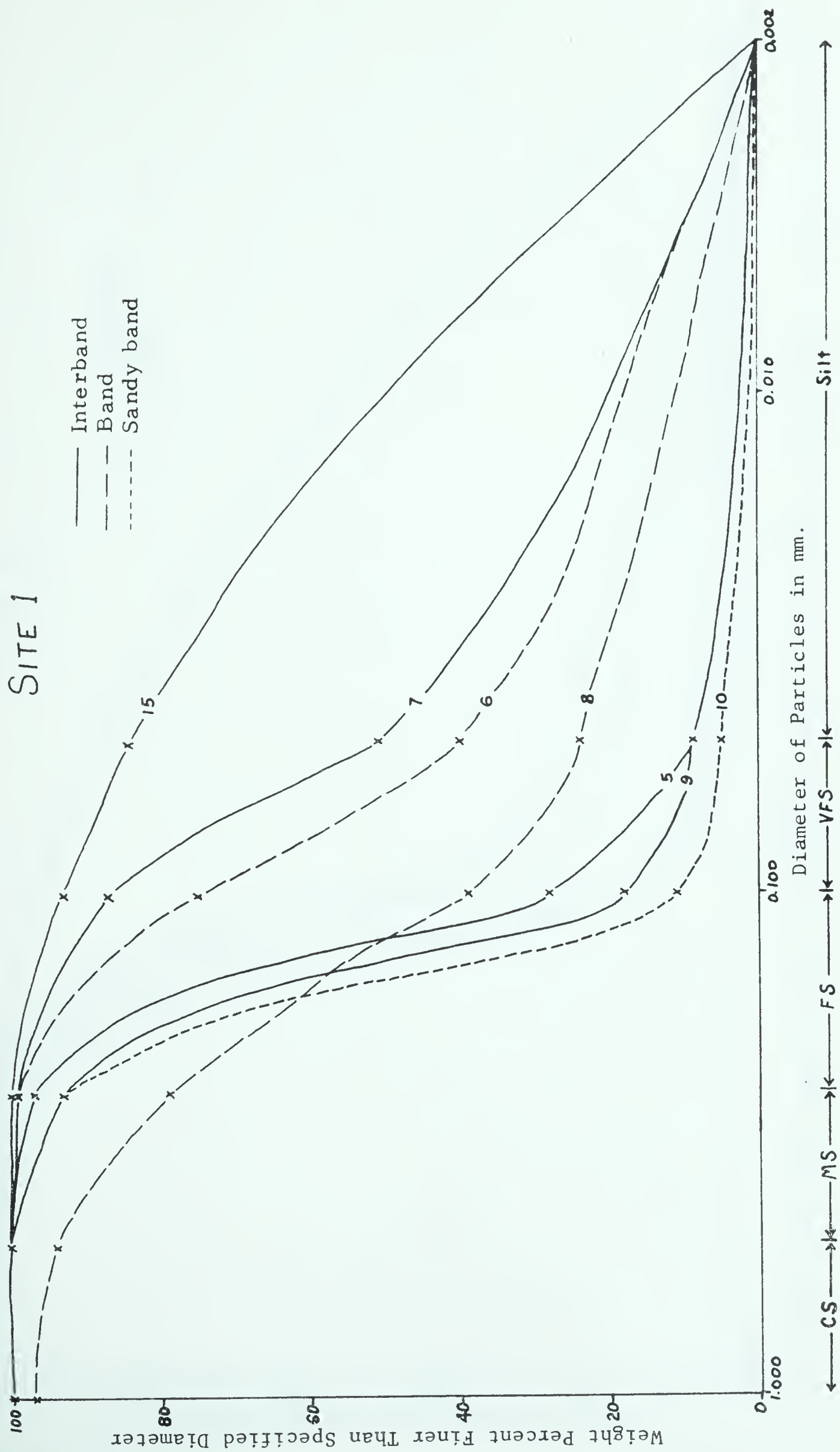


Figure 10 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).



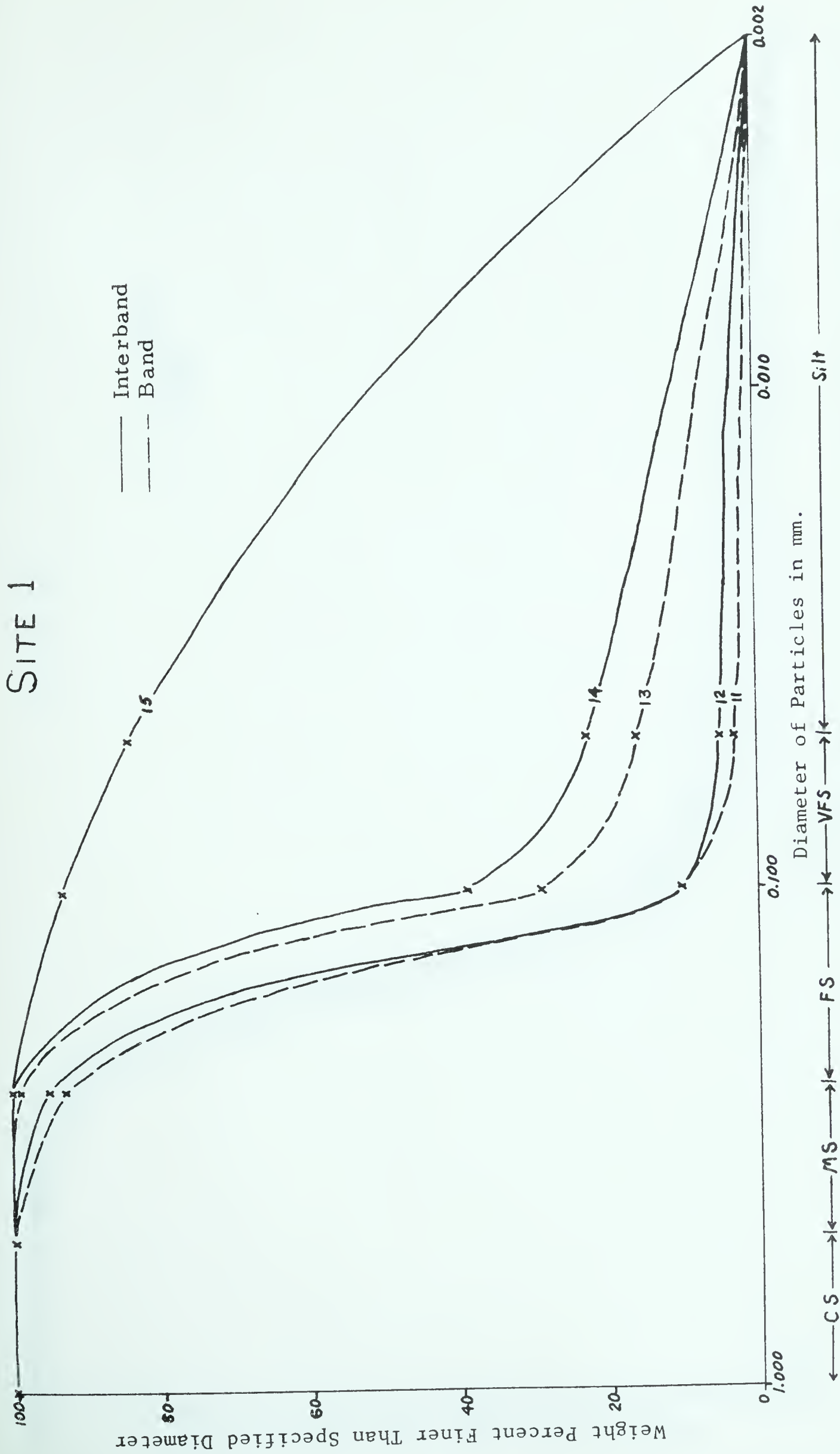


Figure 11 - Cumulative particle size curves ( based on the sum of particles greater than 0.002 mm.).





# SITE 2

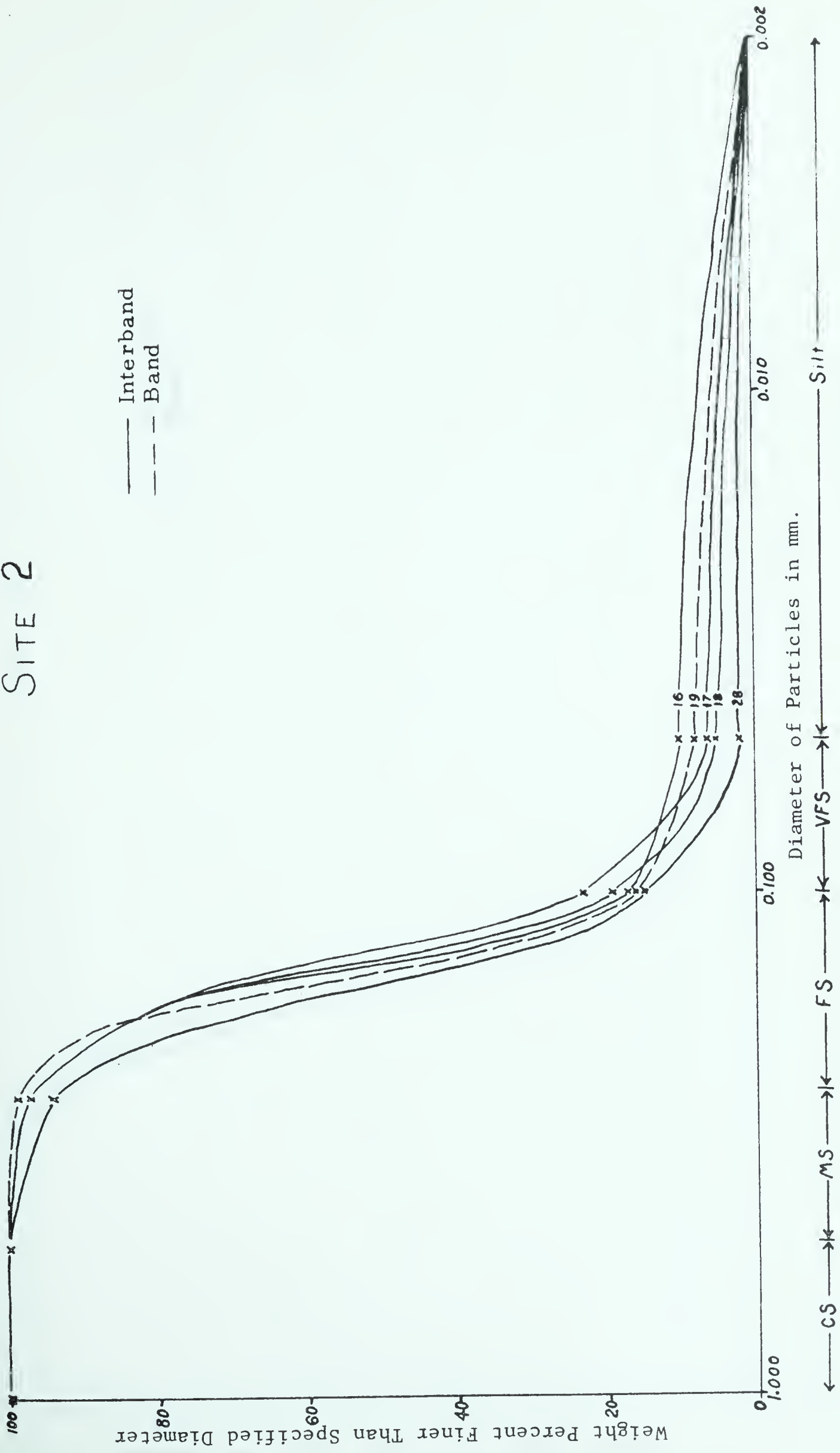


Figure 12 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).



# SITE 2

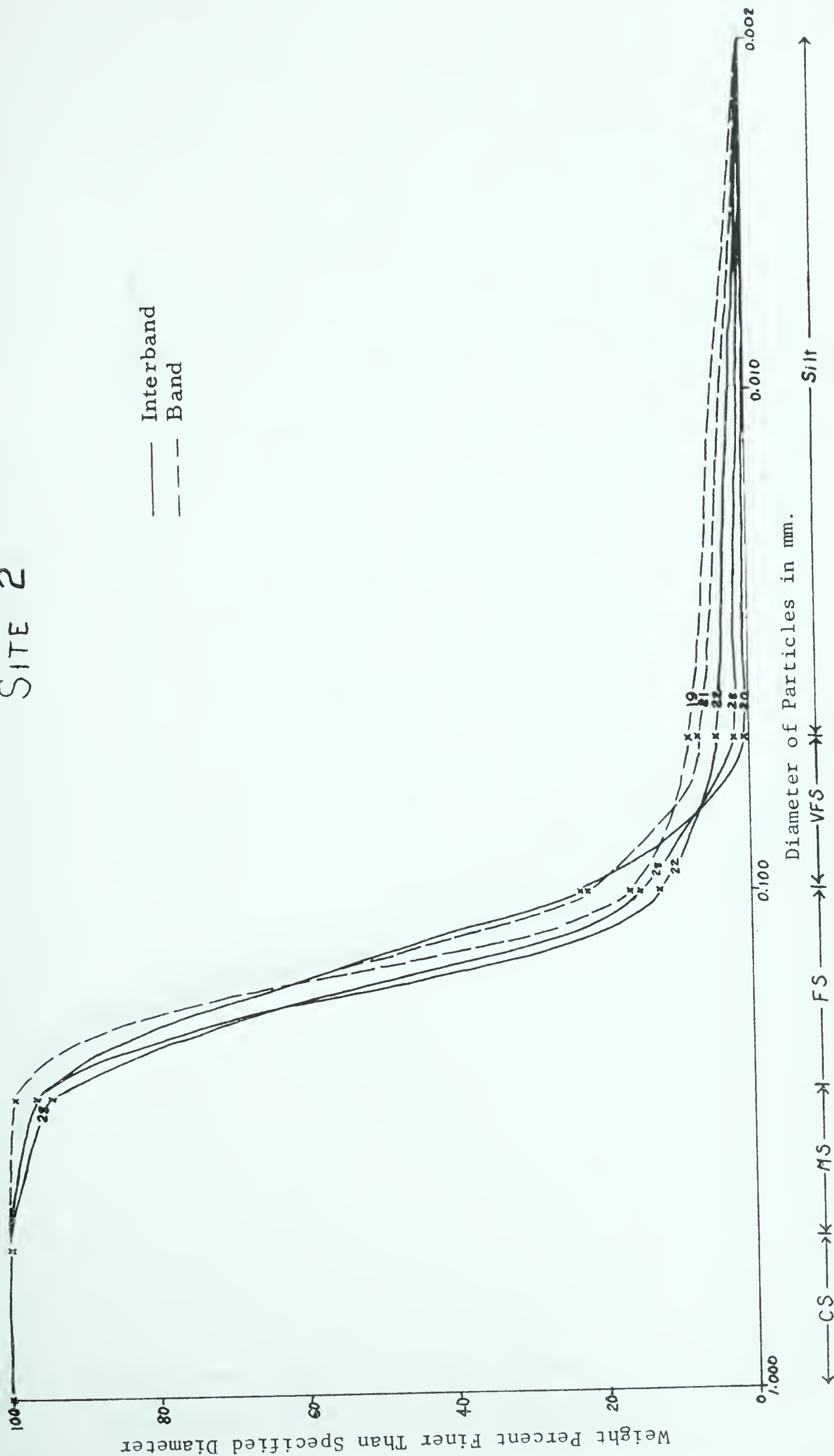


Figure 13 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).



# SITE 2

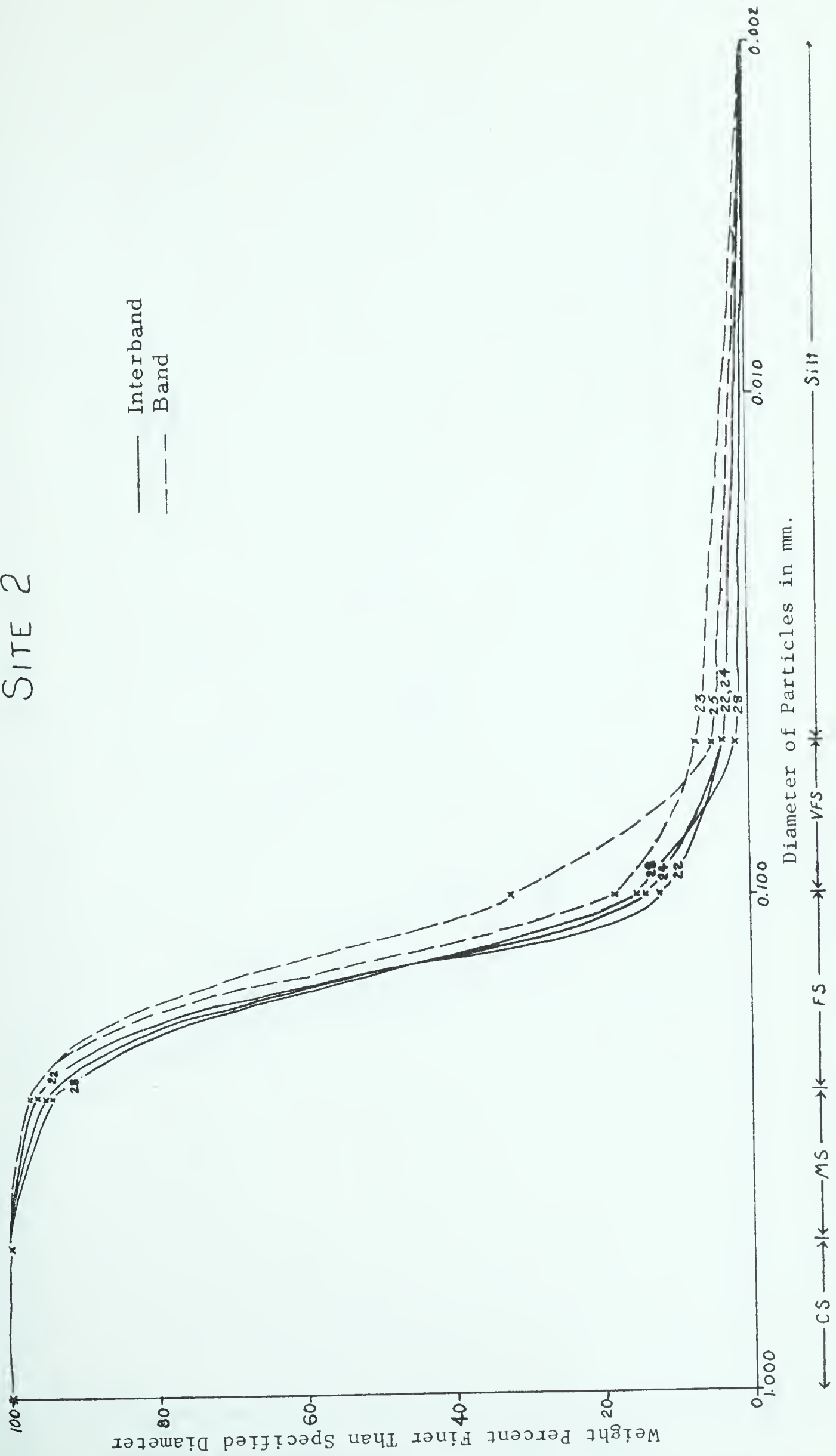


Figure 14 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).





SITE 2

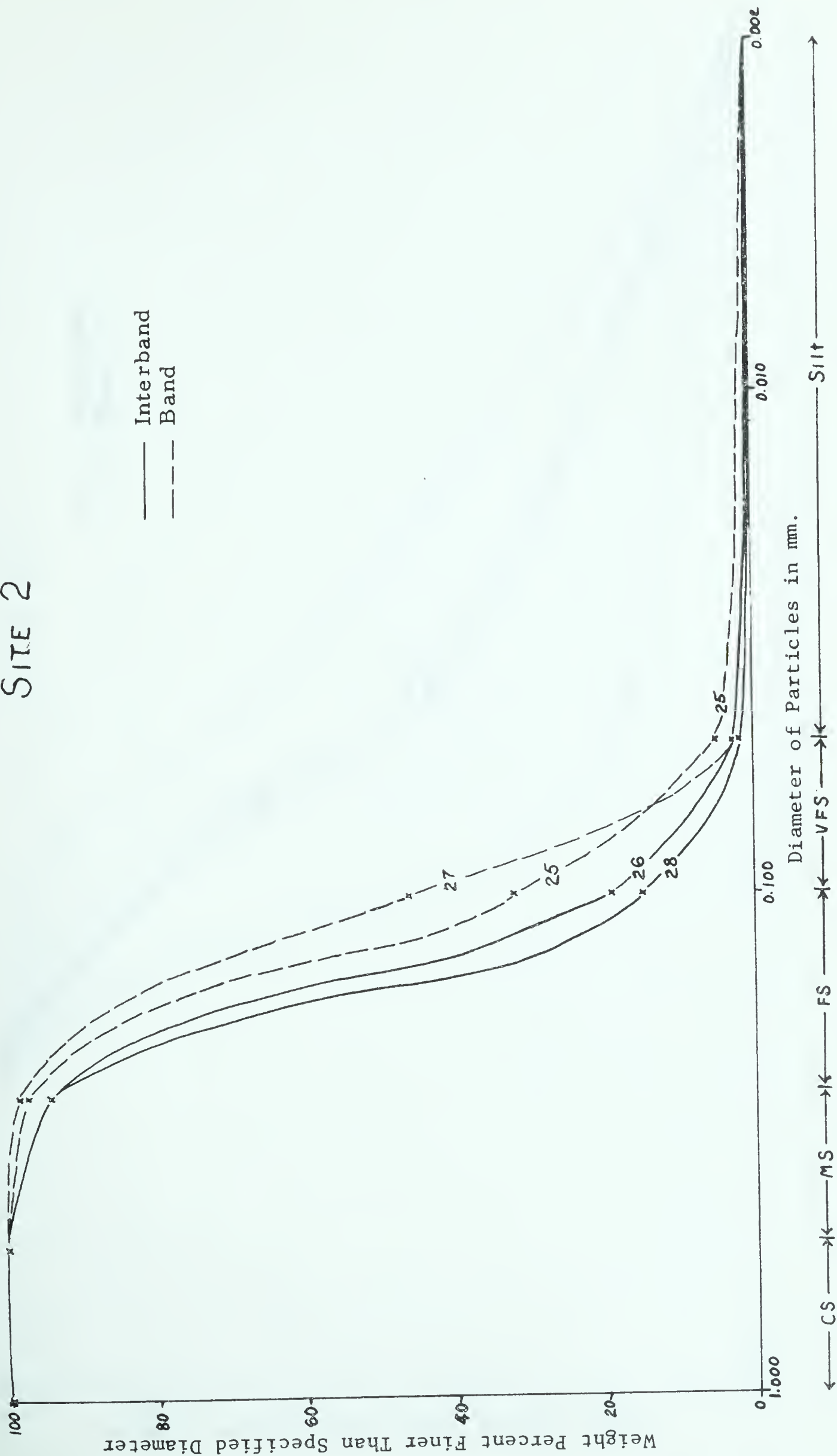


Figure 15 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).



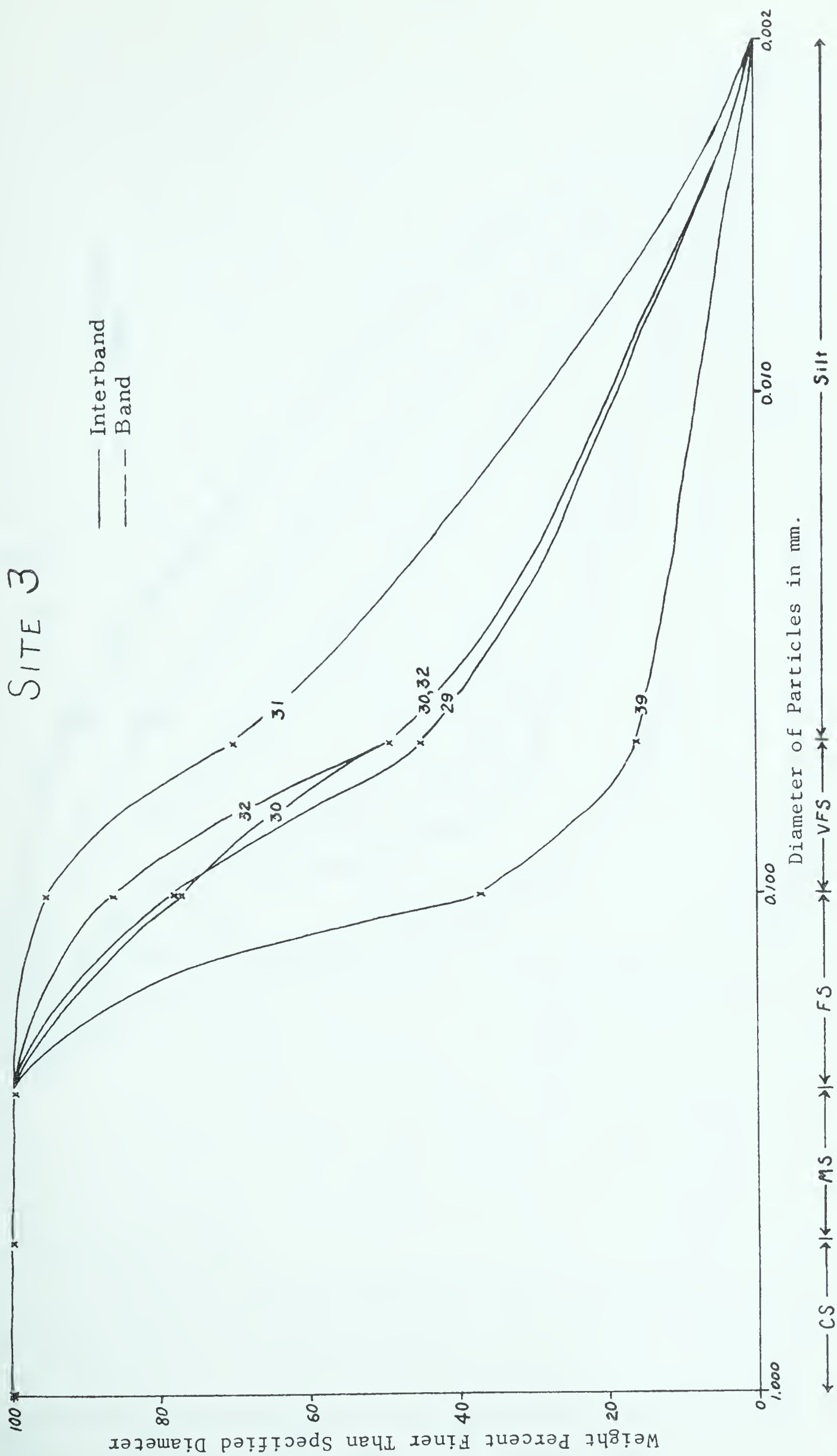


Figure 16 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).





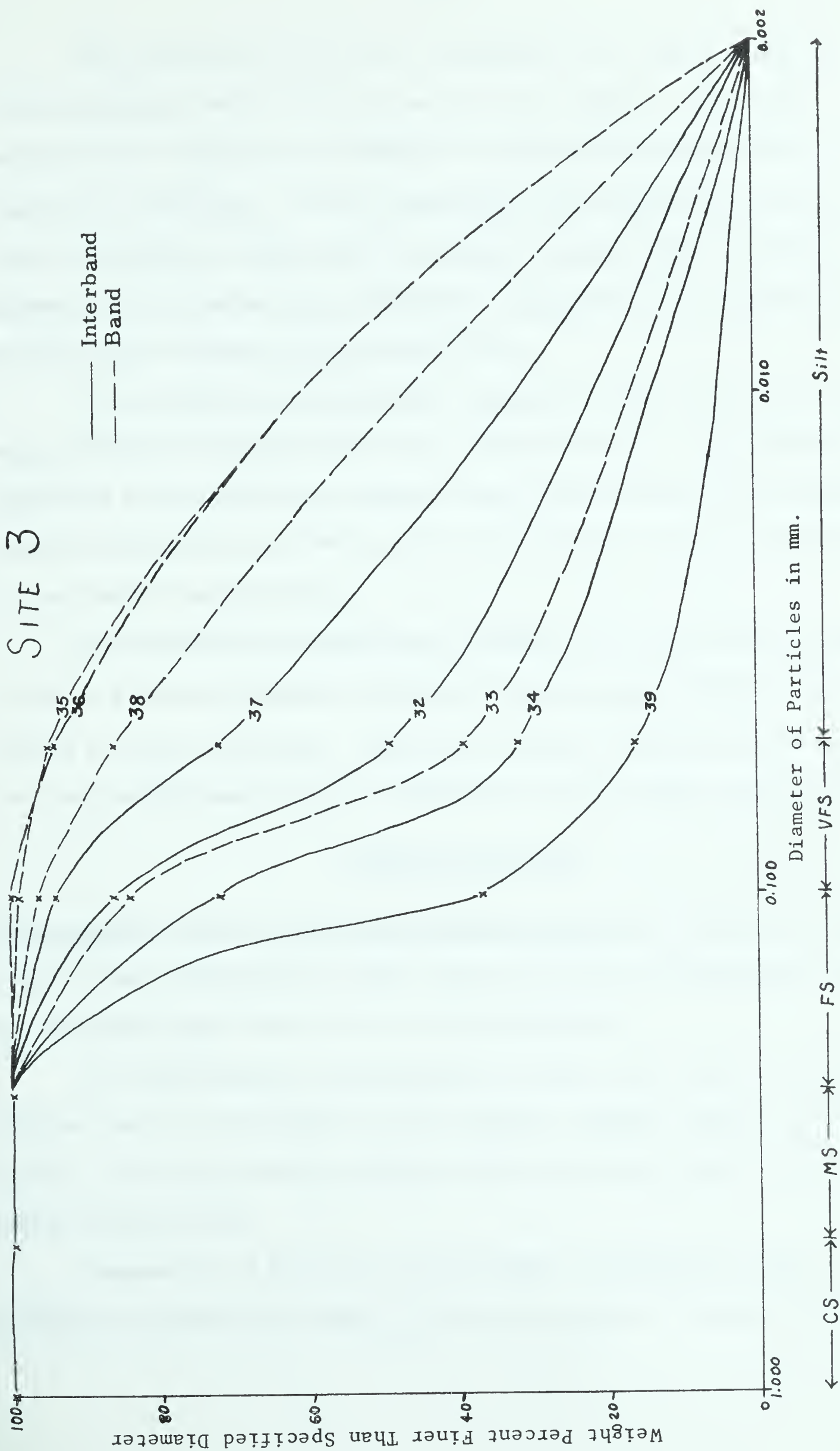


Figure 17 - Cumulative particle size curves (based on the sum of particles greater than 0.002 mm.).



The cumulative curves are calculated on the basis of particle size distribution within the sand and silt size ranges. Since these particles are relatively non-mobile, the influence of pedogenesis is reduced to a minimum. These cumulative curves show quite clearly that considerable stratification is present in some of these profiles. In general the conclusions agree with those suggested by an examination of particle size frequency distribution curves.

The mechanical analysis data suggest that site 1 and site 3 are highly stratified although this is less evident in site 2. It is difficult to determine from mechanical analysis alone, the amount of clay accumulation in the bands that is the result of stratification and the amount that is the result of pedogenesis.

The mechanical analysis data (Tables IV, V, and VI) are similar to that of Folks and Riecken (1956) and Wurman et al. (1959) in their studies on soils with bands. However, in their work the peak distributions are broader and less textural variations are found within single profiles.

### Chemical Analyses

Exchangeable Cations and Cation Exchange Capacity: The cation exchange capacity and exchangeable cations generally reflect the pedogenic processes which have been active in soil development.

The distribution of exchangeable cations in all soils tested showed calcium ions to predominate on the exchange complex (Tables VII, VIII, and IX). The exchangeable calcium content decreases gradually with depth in the profiles.

Magnesium is the next most abundant exchangeable cation and gradually increased with depth in the three profiles. The sum of the



exchangeable calcium plus exchangeable magnesium remains nearly constant within a given profile.

The decrease in per cent exchangeable calcium and increase in per cent exchangeable magnesium with depth is probably the result of preferential translocation of calcium upward by plant growth processes sufficient to overcome the downward tendency of leaching. The increase in exchangeable magnesium with depth likely results from low translocation by plants and does not offset the leaching process.

No consistent difference is apparent between the per cent exchangeable calcium and/or per cent exchangeable magnesium contents in the bands and the interbands.

Exchangeable sodium percentage is very low and increases slightly with depth, but is somewhat erratic. Exchangeable potassium percentage is quite similar to exchangeable sodium percentage although somewhat higher.

Exchangeable acidity is considered to be a measure of the hydrogen ions displaced from the exchange complex as well as the  $H^+$  ions released by hydrolysis of the exchangeable aluminum ions. Exchangeable acidity generally decreases with depth although pH remains relatively constant. No consistent differences are apparent in exchangeable acidity between bands and interbands.

The total exchange capacity as determined by summation differs from that found by direct determination in that the former gives higher results than the latter. A discrepancy in the same direction was noted by Lavkulich (1963). In general the cation exchange capacity by both methods is higher in the bands than the interbands and may be the result of a higher content of exchange complexes in the bands.





Sample 10 collected from a band at a depth of 44 inches in the profile at site 1 did not appear to have higher clay content than the interbands but rather appeared to be more eluviated than adjacent inter-band material. Therefore a low clay content and cation exchange capacity was expected. Sample 31, which is immediately below the Ae horizon in site 3, is comprised of material that is finer in texture and higher in total exchange capacity than the adjacent materials but does not possess the morphological characteristics of a band. This sample may have some illuvial clay present especially when considering its proximity to the Ae horizon.

pH Values: Results for pH values in the profile at site 1 and the profile at site 3 show no relationship to the bands or interbands. In the profile at site 2, however, a trend is evident when bands and interbands are compared. These bands have pH values from 0.4 to 0.7 units lower than the "Ae-like" materials or interband materials. The lower pH values in the bands are probably related to the higher free iron oxide content in the bands which may hydrolyze much like aluminum to increase the acidity. The soil reaction in the three profiles is acid throughout ranging in pH from 5.2 to 6.4. Soil reactions at site 1 and site 2 are consistently lower than at site 3. These results are similar in magnitude to those often found in the solum of Grey Wooded soils (Pawluk, 1961; Lavkulich, 1963).

Calcium Carbonate Equivalent: The pH values for the soils studied indicate that the soils are acidic in all cases. Determinations on the three lowest samples in each profile suggest that only a very low amount of calcium carbonate is present. In view of the pH values found, such results may be expected for these soils. In field observations samples



from as deep as 15 feet at site 1 and 20 feet at site 2 show no evidence of calcium carbonate by field tests. At site 3 at about 5 to 6 feet below the surface calcium carbonate is found to be present in a localized area of soil. The calcium carbonate occurs as blotches 1/2 to 1 inch in diameter and appear more greyish than the matrix material.

Nitrogen and Total Carbon: Total carbon is considered to be a good estimate of organic carbon since calcium carbonate is present either in low quantities or is entirely absent. Both carbon and nitrogen are present only in low amounts especially below the Ah horizon, probably as a result of the generally rapid decomposition of organic materials under forest vegetation. In all profiles studied there is generally more organic matter in the band than the interband region. A similar trend is evident for nitrogen distribution. In the samples from the lower depths of the profile at site 1 the increase in carbon content is probably the result of an increase in the amount of "coal flecks" or carbonized organic matter which is evident in these materials.

Free Iron Oxide: Extractable hydrous oxides in soil profiles generally represent the dissolution of inorganic soil constituents and consequently reflect, to some extent, the degree of chemical weathering which has occurred. The values for free iron oxides were determined by extracting the soil with a hot sodium hydrosulfite solution (Tables VII, VIII, and IX). Relative to the values reported for free iron oxides by Pawluk (1960) and Lavkulich (1963) the values in this report are quite high throughout. The concentrations of free iron oxide found in the profiles at site 1 and site 2 are somewhat lower than in site 3. Only in the case of the sample collected at the lowest depth at site 1 did the iron oxide exceed that which is found in the bands. This is probably explained in part by the





difference in composition between this material and the overlying soil solum as shown by mechanical analysis, which suggests that the material is of different lithological origin. The bands in almost every case contained 1 1/2 to 2 times as much free iron as the above interbands.

### Mineralogical Analyses

X-ray Analysis of Clays: Semi-quantitative estimates of the clay mineral distribution in the clay fraction were made using cation exchange data as well as a comparison of peak intensities as discussed by Weaver (1958).

X-ray diffraction patterns of representative samples are included in Figures 18 to 20. The relative amounts of the minerals present are reported in Tables X to XII.

The X-ray diffraction patterns for the clays suggest the presence of high amounts of montmorillonite in all the samples. There appears to be a fairly constant ratio between kaolinite and illite, both being present in nearly equal amounts. Chlorite is present in trace amounts in samples above the top band in site 1 and site 2. X-ray diffraction patterns suggest the presence of low quantities of mixed layer structures. Fine grained quartz is present in minor to trace amounts in all samples.

In the glycolated samples of the A horizon, especially the Ah horizon, broad, ill-defined  $17 \text{ \AA}$  diffraction peaks are evident. White (1950) has suggested that illite can weather to montmorillonite with a resulting broad peak between  $10 \text{ \AA}$  and  $17 \text{ \AA}$ . Grim (1953) has suggested that organic molecules can enter into the interlattice spacings of montmorillonite. This led Lavkulich (1963) and Arshad (1964) to suggest that naturally occurring organic molecules in the interlattice spacings may prevent complete glycolation to give a sharp  $17 \text{ \AA}$  peak.



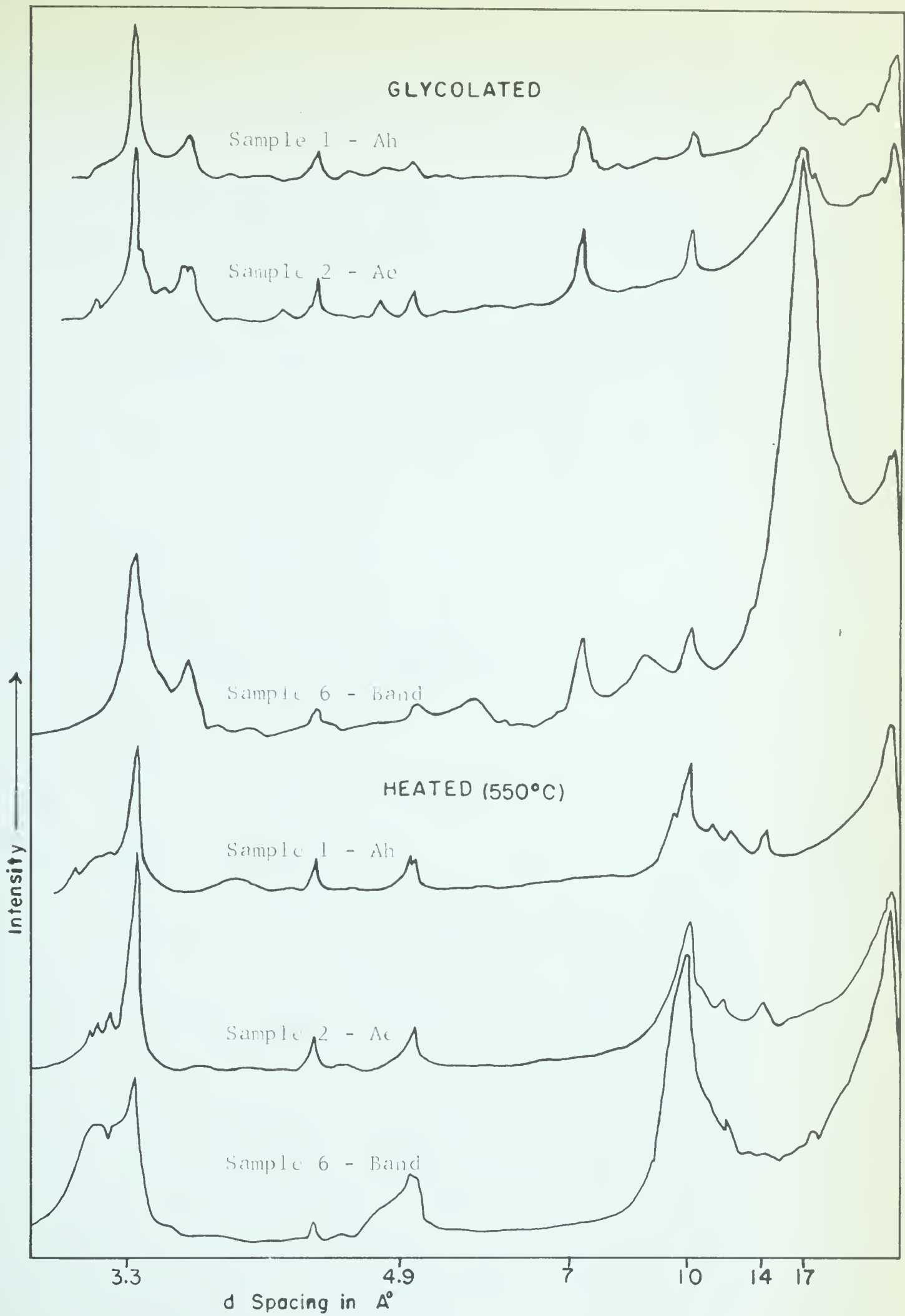


Figure 13 - Characteristic X-ray diffraction patterns for clay minerals in soils at Site 1.



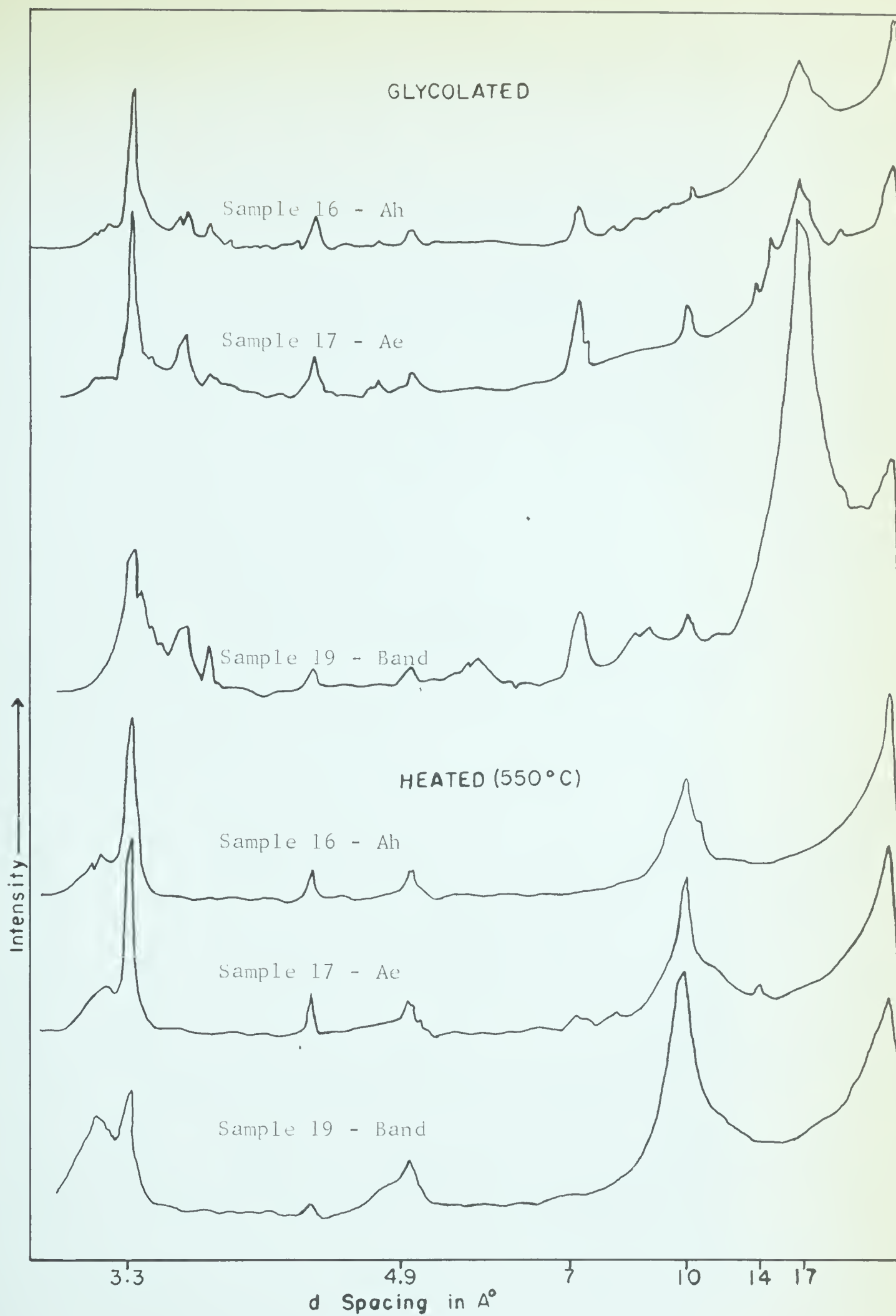


Figure 19 - Characteristic X-ray diffraction patterns for clay minerals in soils at Site 2.





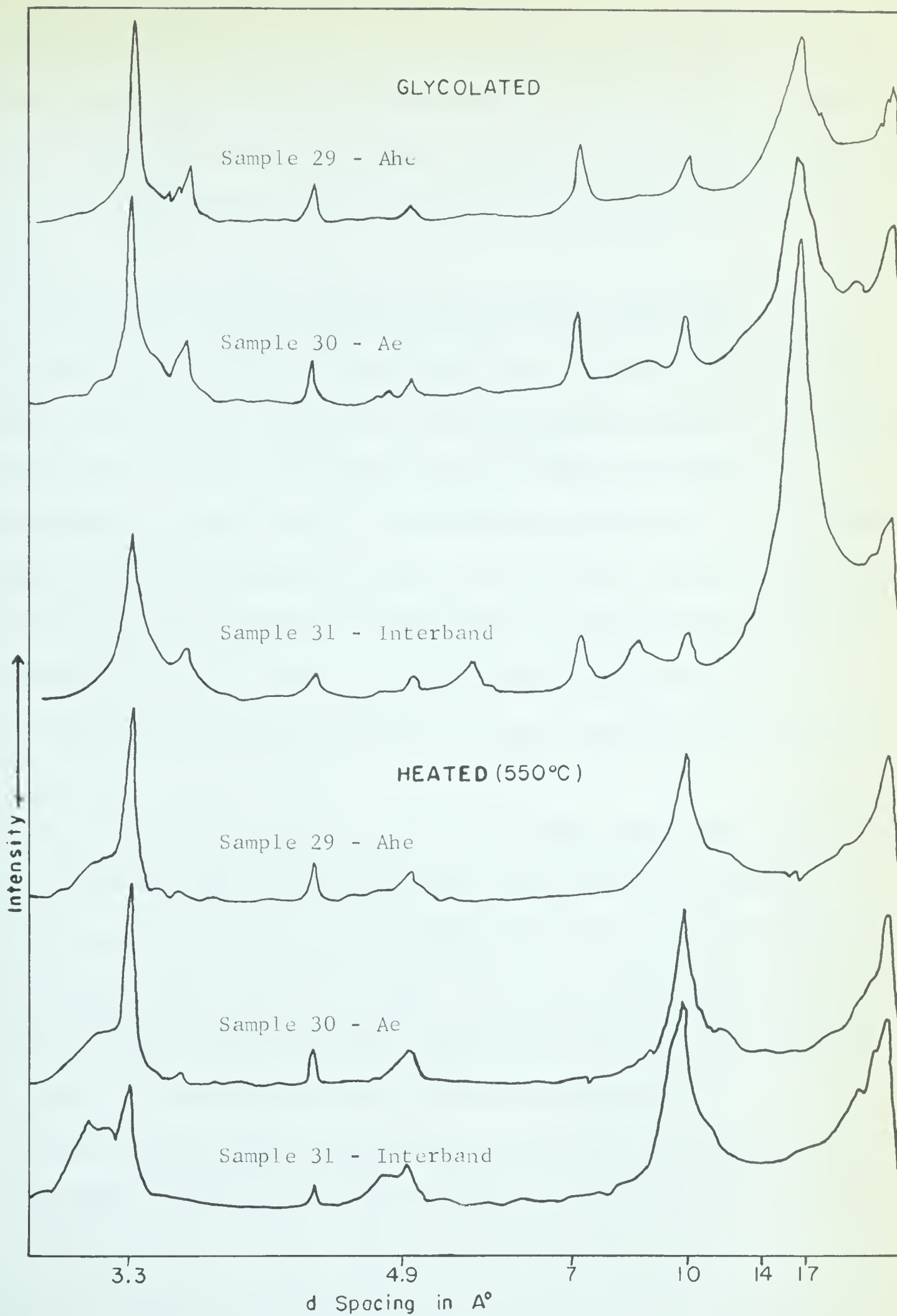


Figure 20 - Characteristic X-ray diffraction patterns for clay minerals in soils at Site 3.



In the profiles studied the clays from the samples above the first band are characterized by X-ray diffraction peaks which show different patterns compared to the clays below the first band. In addition the ratio of peak intensities for montmorillonite to illite and/or kaolinite is less in the material above the top band than in the material below the top band.

According to Weaver (1958) montmorillonite-illite and montmorillonite-chlorite mixed layer clays are common. The mixed layer clays can usually be identified after the samples have been glycolated. If the peak does not shift completely to  $17 \text{ \AA}$  there are some non-montmorillonitic layers present, either illite or chlorite. If the sample is heated to  $550^{\circ}\text{C}$ . and the peak shifts to  $9.5$  to  $10 \text{ \AA}$  the non-expanding layers must be  $10 \text{ \AA}$  material, usually illite. If the peak does not shift completely to the  $10 \text{ \AA}$  position, some chlorite layers are probably present and the clay is likely an illite-chlorite-montmorillonite inter-growth.

In the clays from above the top band, especially in site 1 and site 2, a broad shoulder on the high angle side of the  $17 \text{ \AA}$  peak in glycolated samples is noted. Upon heating to  $550^{\circ}\text{C}$ . a shoulder appears on the low angle side of the  $10 \text{ \AA}$  peak. Thus, chlorite-montmorillonite and chlorite-illite-montmorillonite mixed layer minerals are indicated. In site 3 this mixed layered material is not as prominent.

In the heated ( $550^{\circ}\text{C}$ .) clays from samples below the first band, the  $10 \text{ \AA}$  peak is always skewed toward the high angle side of the peak. This is not evident in the clay minerals above the first band. The skewness suggests a fairly broad range of "d" spacings in the collapsed,  $10 \text{ \AA}$  material which may be the result of illite weathering and/or illite-montmorillonite mixed layer materials. The fact that only a small





shoulder exists on the low angle side of the  $10\text{ Å}$  peak implies that illite-chlorite-montmorillonite mixed layer materials are negligible in clays from samples below the top band. The broad, flat topped glycolated peaks in the vicinity of  $10\text{ Å}$  probably represent more strongly weathered illite or an increased content of mixed layer minerals.

The per cent montmorillonite in the clay fraction appeared to be somewhat higher in the band region than the interband region. This was most evident in the X-ray diffraction patterns for the clay fraction at site 2. The cation exchange capacity of the clay fraction was generally greater in the band regions than the interband regions, especially in the profile from site 2. This higher cation exchange capacity suggests that there is a higher content of montmorillonite in the band than the interband region. Expanding lattice clays disperse and move through the soil more easily than non-expanding lattice clays (Grossman et al., 1959). Thus a genetic accumulation is suggested for some of the clays in the bands of the profiles studied.

Specific Gravity Separations of Sands: The 0.10 to 0.15 mm. sand fraction was separated by a heavy liquid flotation method into minerals heavier than and lighter than sp. gr. 2.96 using tetrabromoethane. The distribution of "light" (sp. gr. less than 2.96) and heavy (sp. gr. greater than 2.96) and the ratio of "light" to heavy minerals is shown in Table XIII.

In site 1 and site 3 the variations in mineralogical composition between samples is apparent although no predictable trend is evident. In site 2 variations in mineralogical composition are not as evident.

Light Mineral Analysis: The identification and chemical composition of the light minerals in soils is of great importance when studying soil



weathering processes. The constituents of the light mineral fraction by their variations in amount through the profile provide a qualitative estimate of soil development.

Silica:alumina ratios (Tables IV, V, and VI) were used as a measure of uniformity in distribution of feldspars as well as an index of weathering. In the profiles at site 1 and site 2 the silica:alumina ratios decrease with depth. In the above instances, silica:alumina ratios increase in the lower portion of the profile and then decrease to a minimum in the samples taken at the greatest depths. The silica:alumina ratio generally decreases with depth in the profile at site 3 until near the bottom of the profile where a definite increase is noted. This is probably the result of mineralogical stratification.

Silica, in the form of quartz, is stable while feldspars are considered less stable against weathering (Bear, 1964; Marshall, 1964). The trend for silica:alumina ratio to decrease with depth suggests that some weathering has occurred, but the magnitude of change in ratio suggests that such weathering is slight. The wide variation in sodium and potassium content among different samples is also evident in the replicates. No reason for such variations could be found in the course of the investigation but may be due to contaminated chemical reagents. For this reason no attempt is made to establish potash feldspar and soda-calcic feldspar content.

### Microscopic Analyses

Mineral Grain Frosting: The very fine sand fraction was examined under reflected light for evidence of grain frosting with the aid of a petrographic microscope. Plate 3 illustrates the appearance of the mineral grains. Since most of the mineral grains are quartz they do not weather easily.





Therefore, precipitation rather than weathering coatings are likely to be of more common occurrence.

About 40 to 50 per cent of the grains appear to be frosted. There is also a considerable number of grains with coatings, which appear dark in plane light. It is difficult to tell whether some of the very whitish grains in reflected light (as in the bottom center of Plate 3, picture 3) are frosted or just coated. These often appear dark in plane light indicating some coatings but not eliminating the possibility of the occurrence of frosting below the coatings.

Thin Sections: Thin sections are useful in the identification of stratified materials, both mineralogic and textured. They also are of considerable value in determining the mechanism of clay accumulations, as well as identifying iron and organic matter accumulations.

Thin sections of the band and interband regions were studied using the petrographic microscope (Plates 4 to 12). In the profiles at site 1 and 2 the fabric probably corresponds to the intertextic and porphyro-skelic fabrics as used by Brewer (1964). The profile at site 3 has a denser fabric than those at site 1 or site 2 but is still probably porphyroskelic. The thin sections show the fabric to change in density over relatively short horizontal distances. Variations in density of fabric and in particle size distribution occur throughout the profile. The changes in fabric follow little, if any, predictable pattern although the bands seem to have a denser fabric than the interbands. Texture differences indicate horizontal stratification of materials. Samples from site 1 and site 3 have the largest particle size distribution variations within the profiles. Site 3 has considerably more particles of fine grained size than either site 1 or site 2.





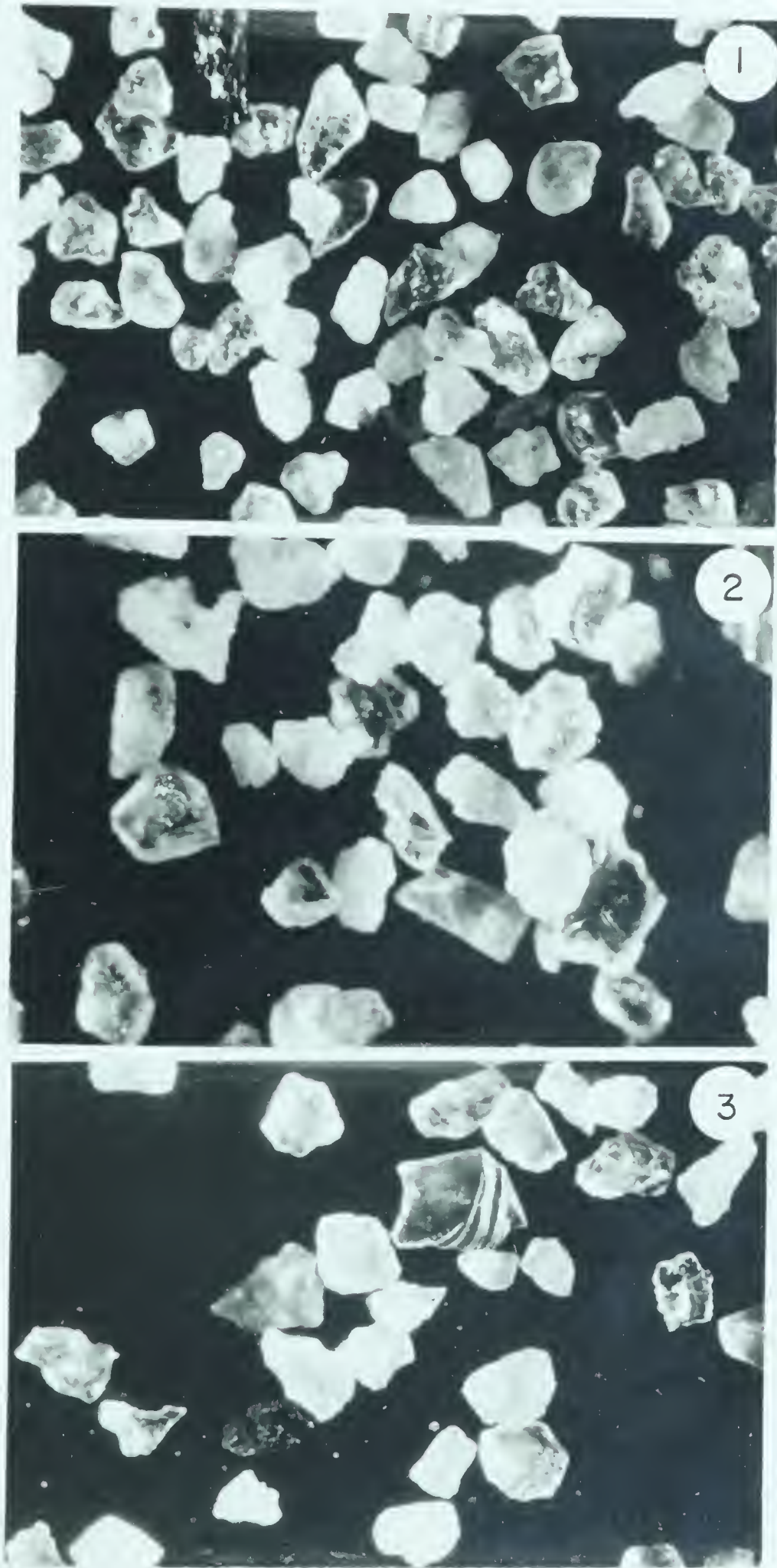


Plate 3. Photomicrographs of the 0.10 to 0.15 mm. sand fraction showing grain frosting and grain coatings.



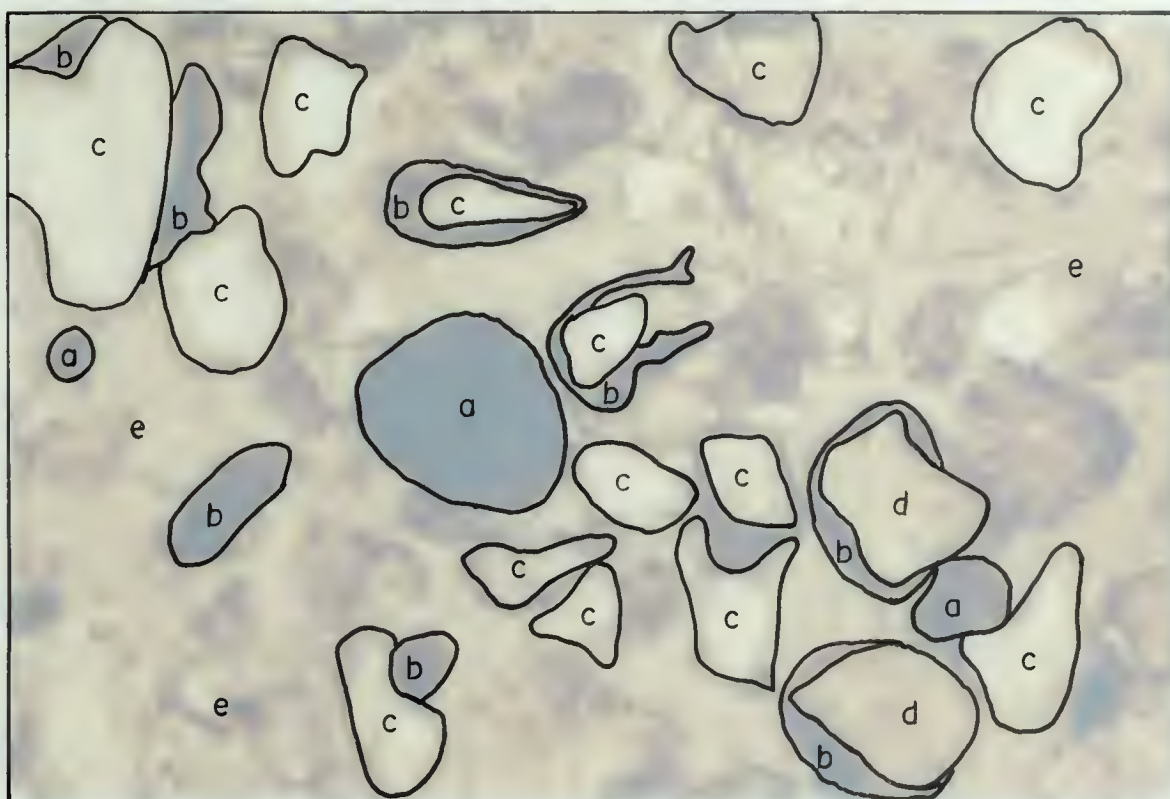
Description of Plate 3

- Picture 1    Photomicrograph of the very fine sand fraction of site 1, sample 1, showing frosted mineral grains.
- Picture 2    Photomicrograph of the very fine sand fraction of site 1, sample 5, showing frosted mineral grains.
- Picture 3    Photomicrograph of the very fine sand fraction of site 3, sample 29, showing frosted mineral grains.





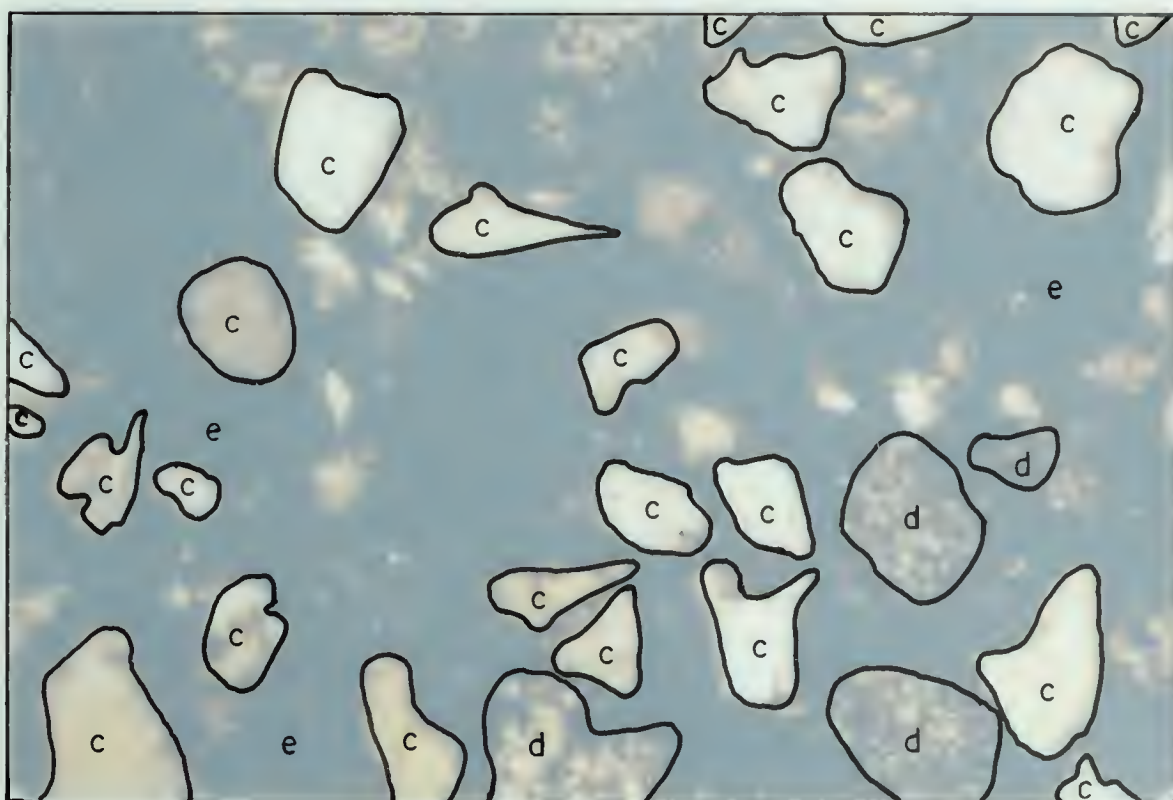
Schematic Diagram of Plate 4



Plane  
light

LEGEND

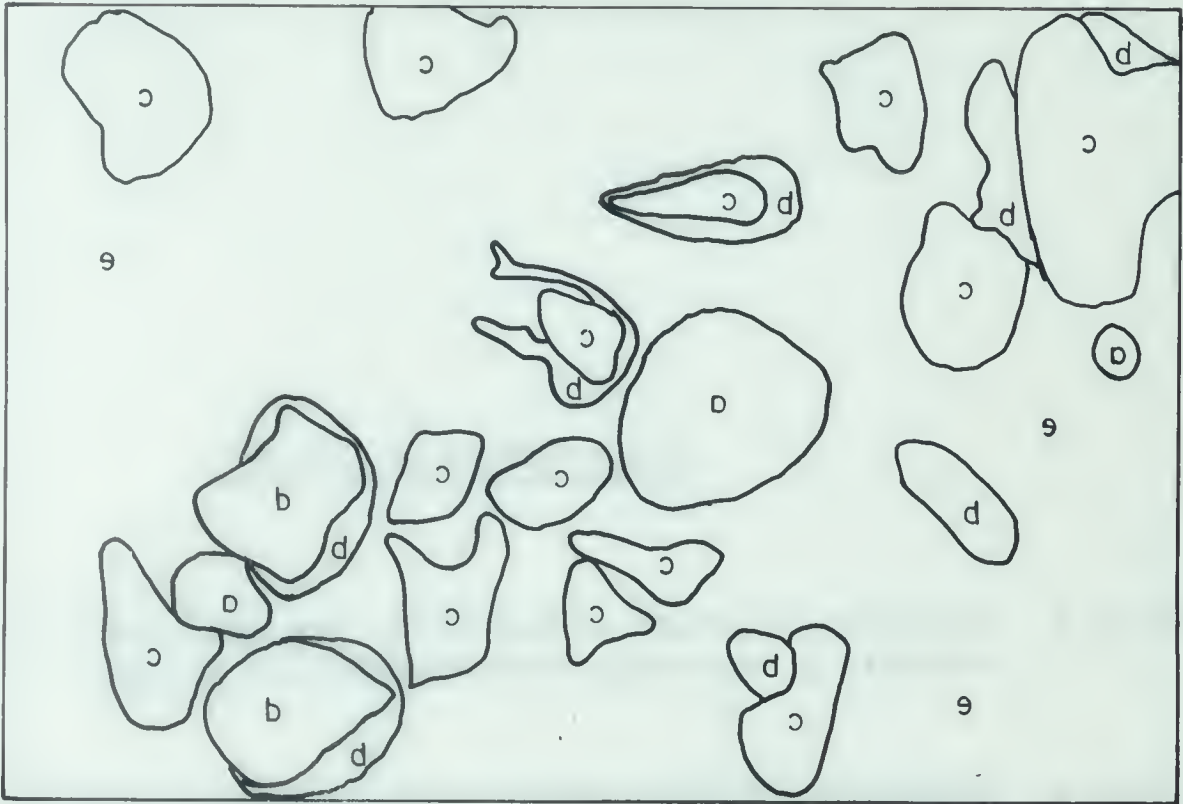
- a) Organic-iron  
nodules
- b) Organic-iron  
coatings
- c) Large mineral  
grains
- d) Weathered  
minerals
- e) Voids and matrix



Crossed  
Polarizer

Plate 4. Photomicrograph of the "Ae - like" material sampled at Site 2 (horizontal).

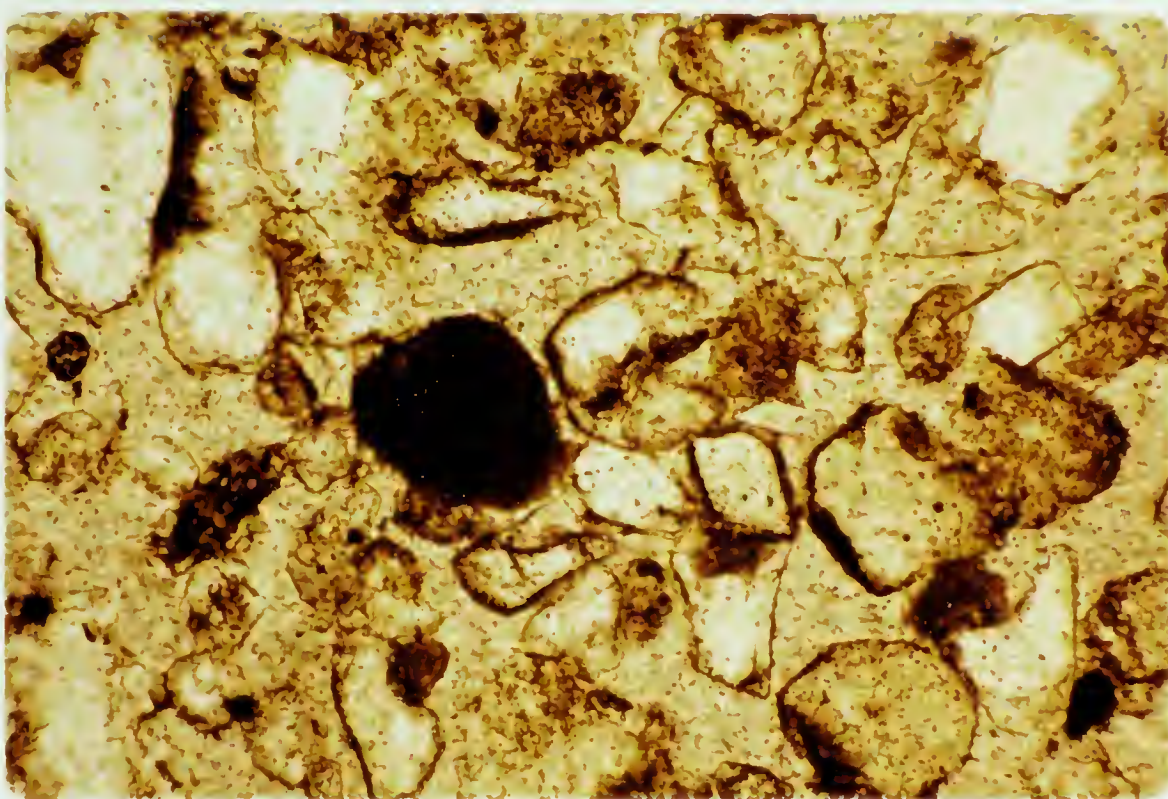
Schematic Diagram of Plate 4



LEGEND  
a) Organic-iron nodules  
b) Organic-iron coatings  
c) Large mineral grains  
d) Weathered minerals  
e) Voids and matrix

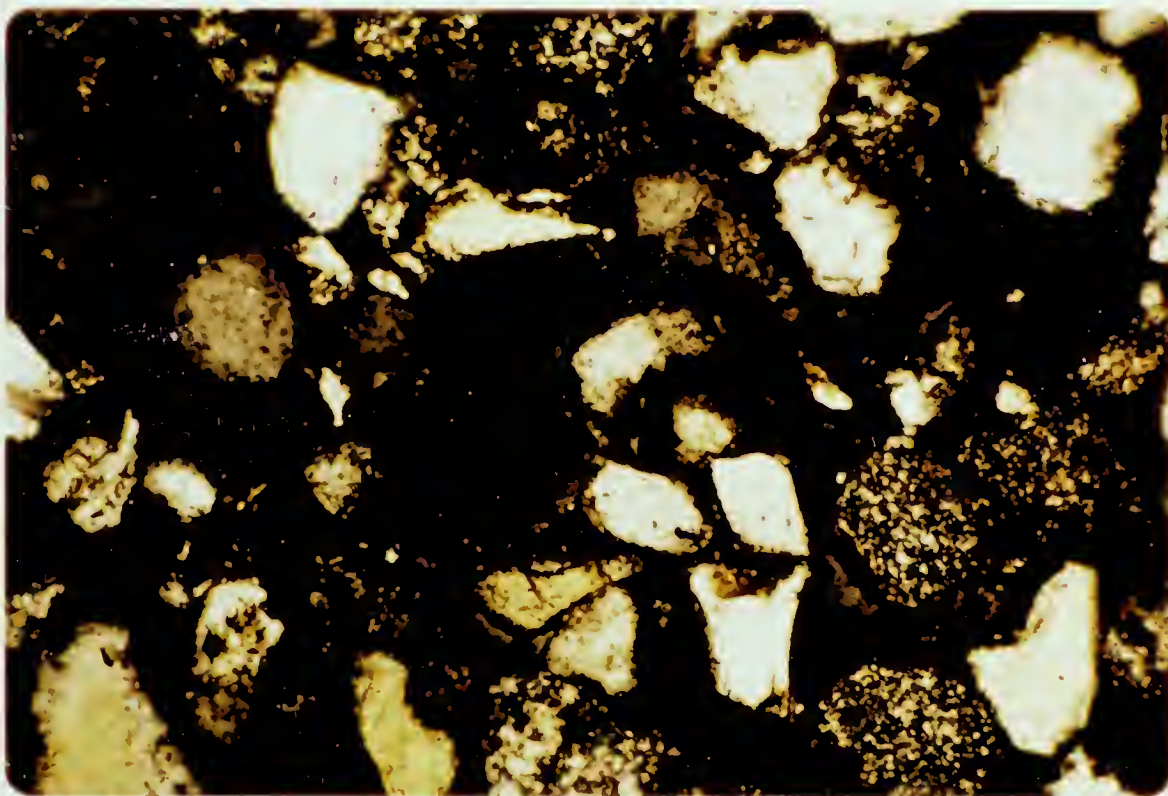






Plane  
Light

← 1.0 mm. →



Crossed  
Polarizers

Plate 4. Photomicrograph of the "Ae - like" material sampled at Site 2 (horizontal).



Description of Plate 4

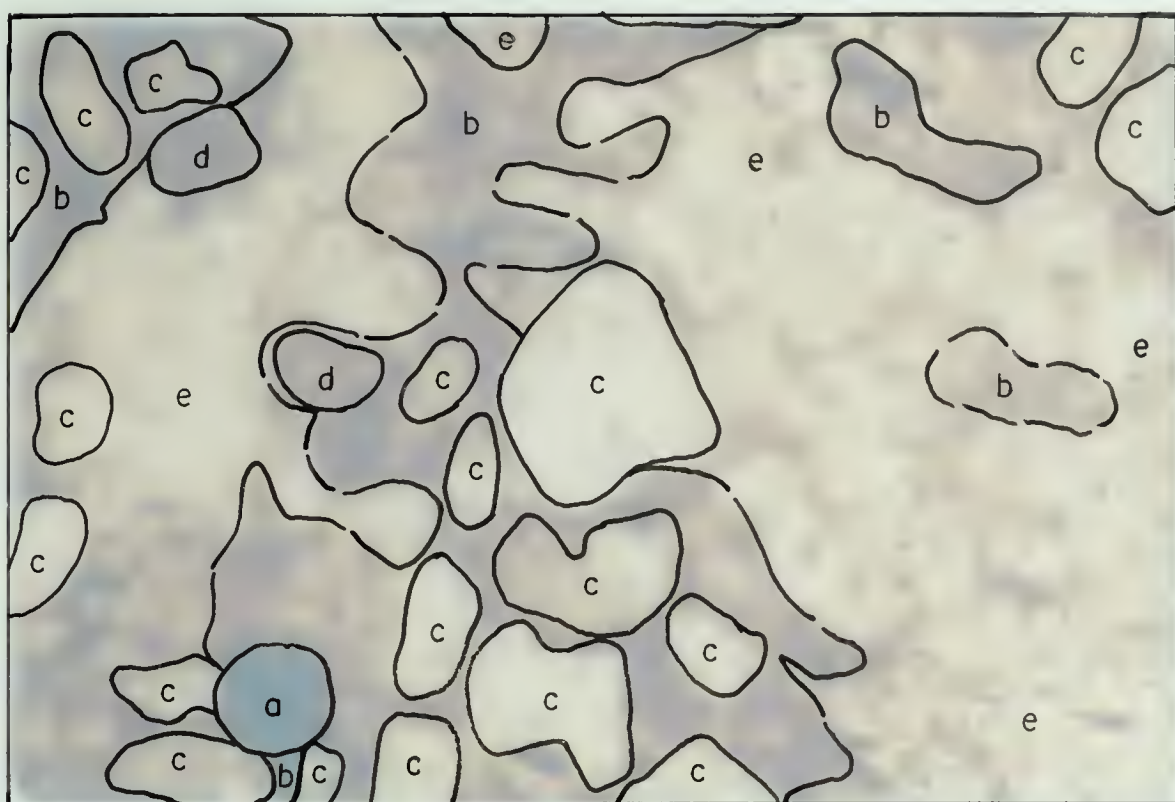
Plate 4 is a photomicrograph of a sample from the "Ae-like" material in the profile at site 2. The fabric is similar to the granular fabric as described by Brewer (1964). The dark nodule<sup>1</sup> is considered to be co-precipitated iron and organic matter. These nodules are quite prevalent in the "Ae-like" material. There are few coatings on the mineral grains and those present are opaque in plane light, likely consisting of amorphous iron and organic matter. Most of the material between the grains is impregnating material and debris from grinding. There are a number of weathered mineral grains evident.

<sup>1</sup> Defined by Brewer (1964) as a concentration of materials with undifferentiated internal fabric.





# Schematic Diagram of Plate 5

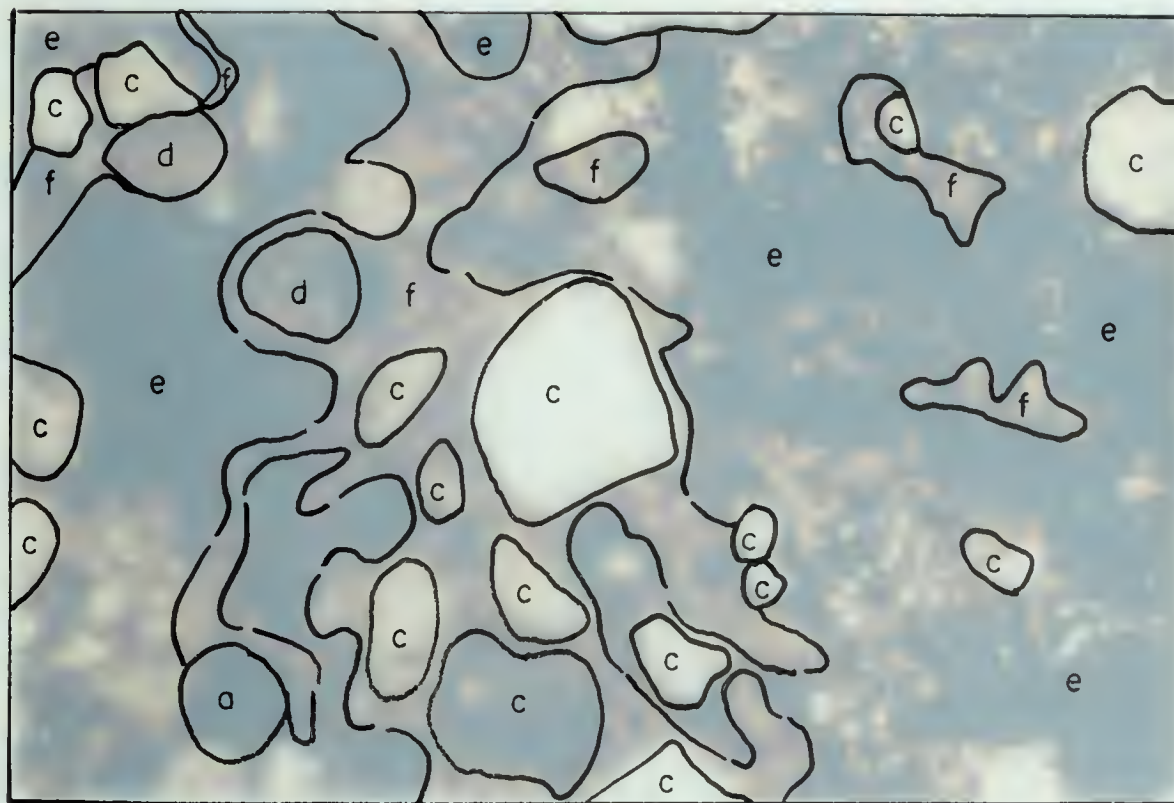


Plane  
Light

## LEGEND

- a) Organic-iron nodules
- b) Iron-clay concentrations
- c) Large mineral grains
- d) Weathered minerals
- e) Voids and matrix
- f) Oriented clay

1.0 mm.



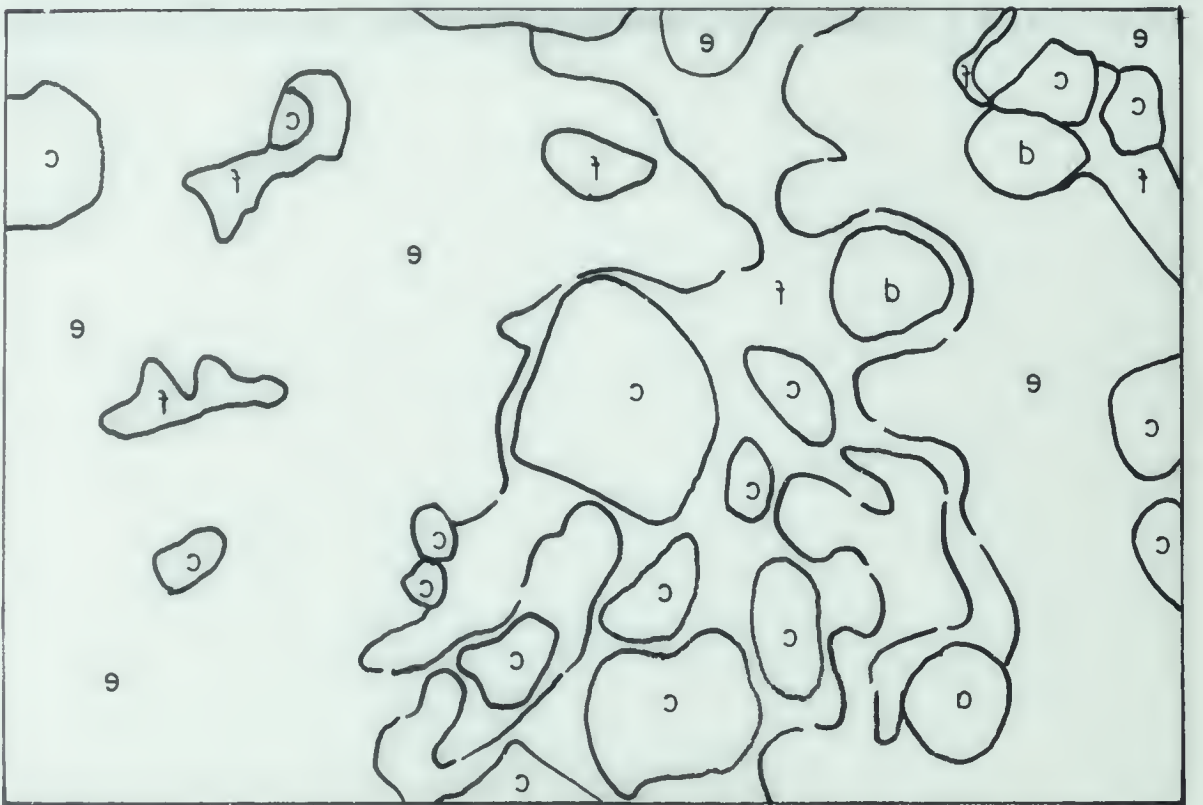
Crossed  
Polarizers

Plate 5. Photomicrographs of the top band, sampled at site 1 (1000x).

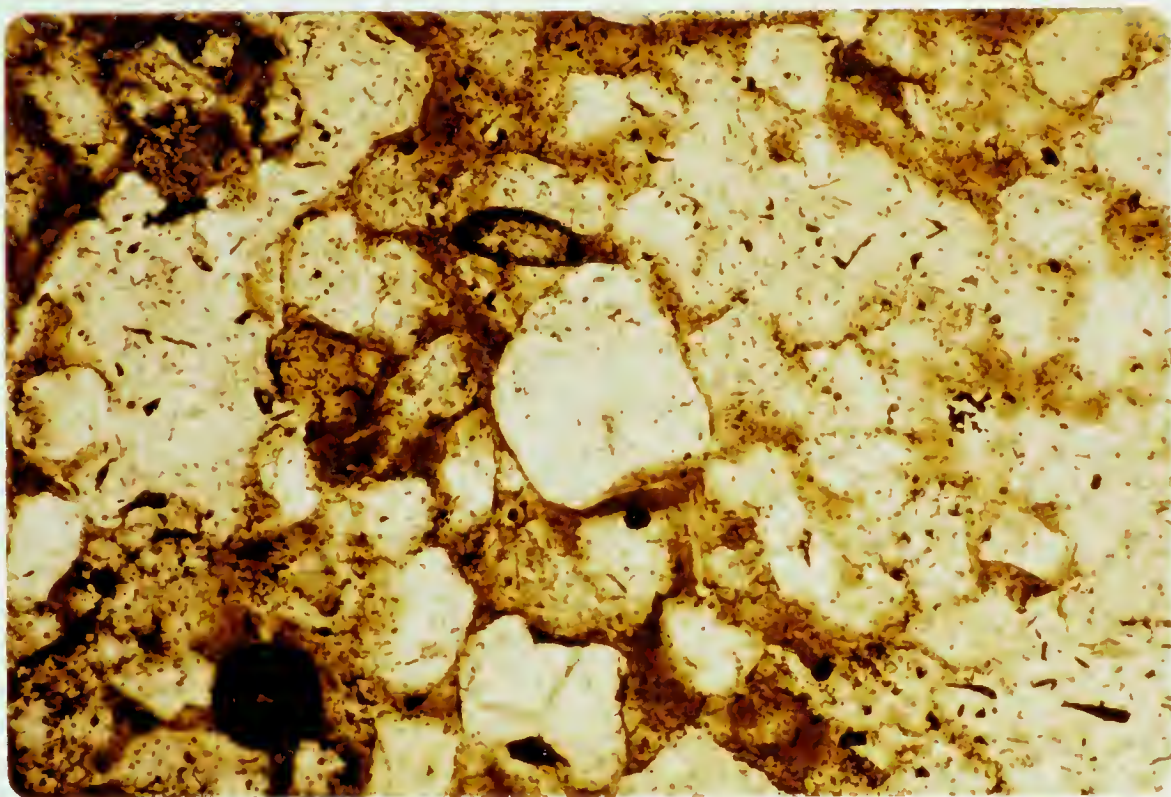
Schematic Diagram of Plate 2



- LEGEND
- a) Organic-iron nodules
  - b) Iron-clay concentrations
  - c) Large mineral grains
  - d) Weathered minerals
  - e) Voids and matrix
  - f) Oriented clay

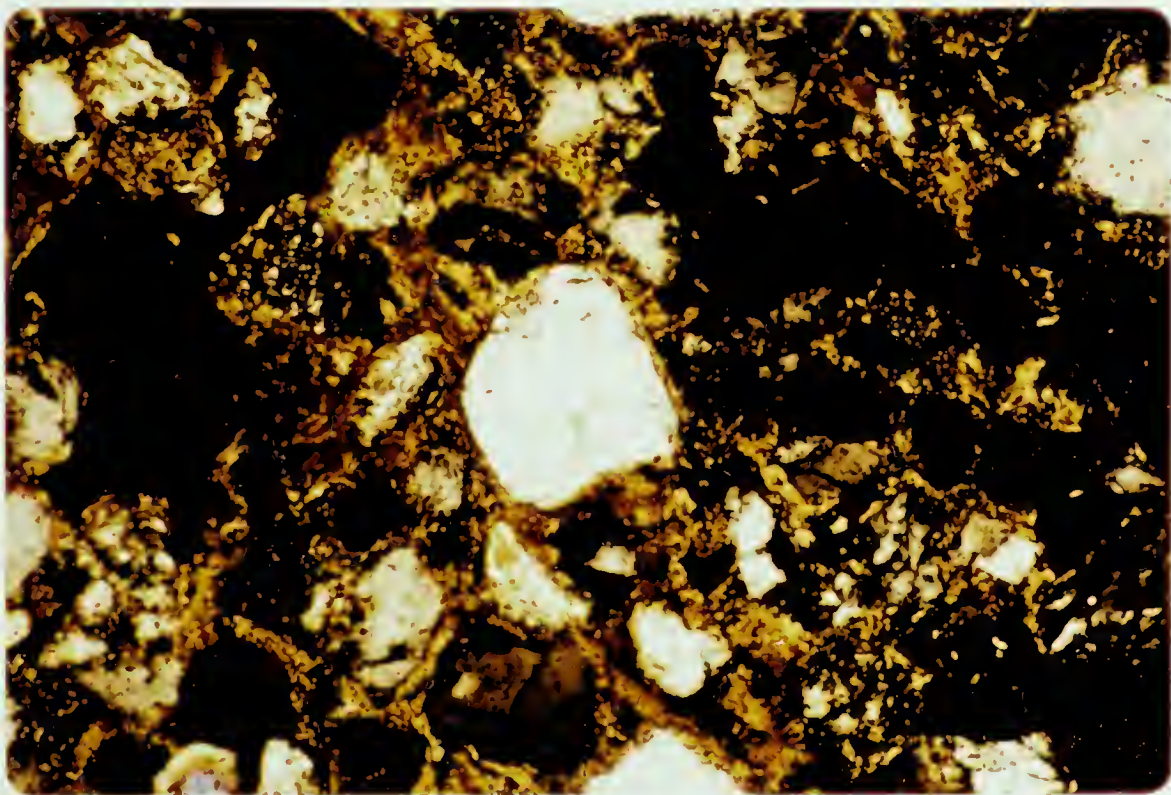






Plane  
Light

← 1.0 mm. →



Crossed  
Polarizers

Plate 5. Photomicrograph of the top band, sampled at Site 2 (horizontal).



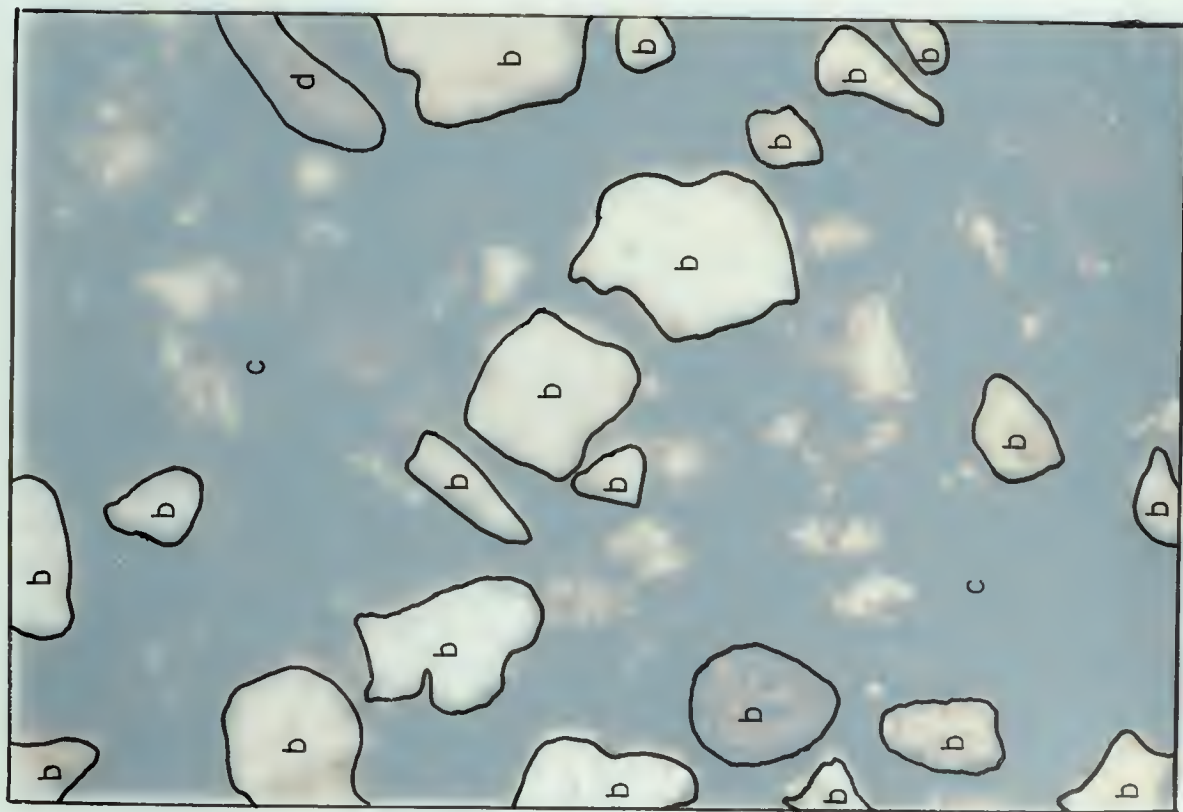


Description of Plate 5

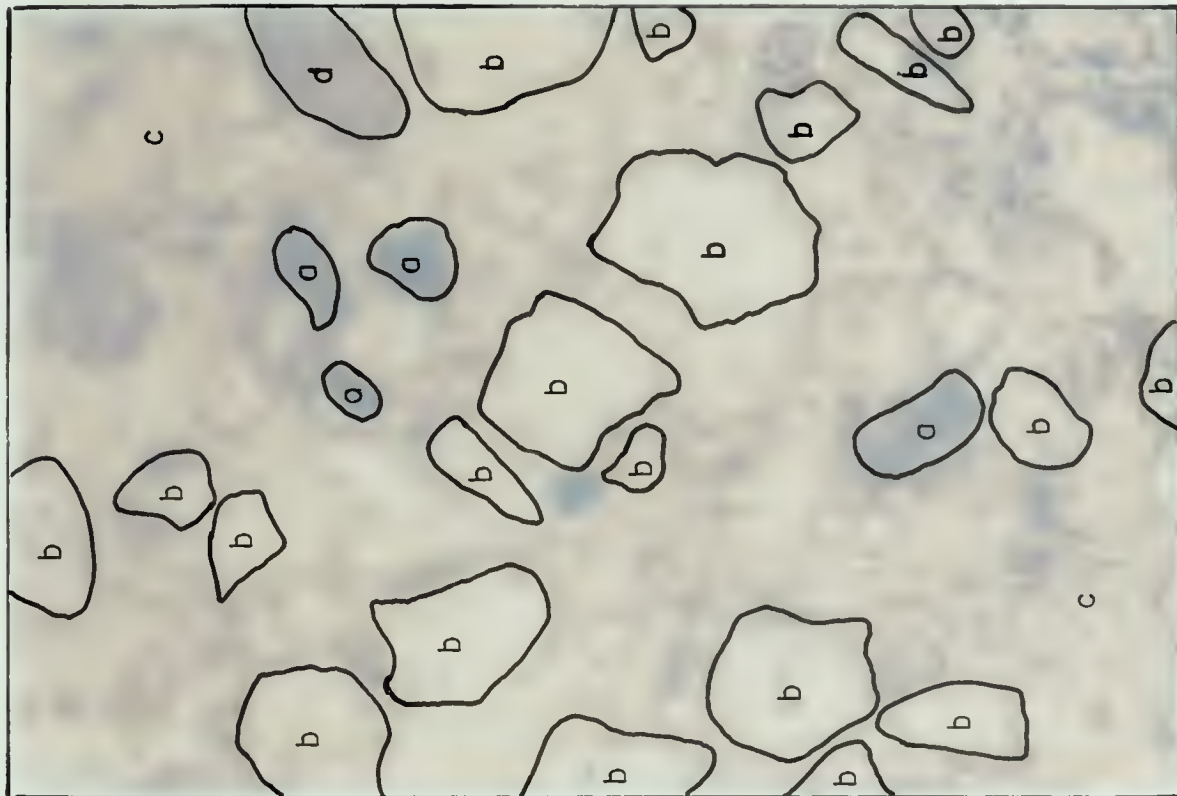
Some of the characteristics of the top band in the profile at site 2 are depicted by Plate 5. The fabric is similar to the intertextic fabric as described by Brewer (1964). There is some accumulation of clay as well as the accumulation of iron in the form of cutans on the mineral grains. An increased evidence of coatings and cutans is found in the band regions as opposed to the "Ae-like" or interband regions as shown by a comparison of Plates 4, 5, and 6. There is also more plasma than in Plate 4, nearly all of which is oriented (as seen under crossed polarized light).



# Schematic Diagram of Plate 6

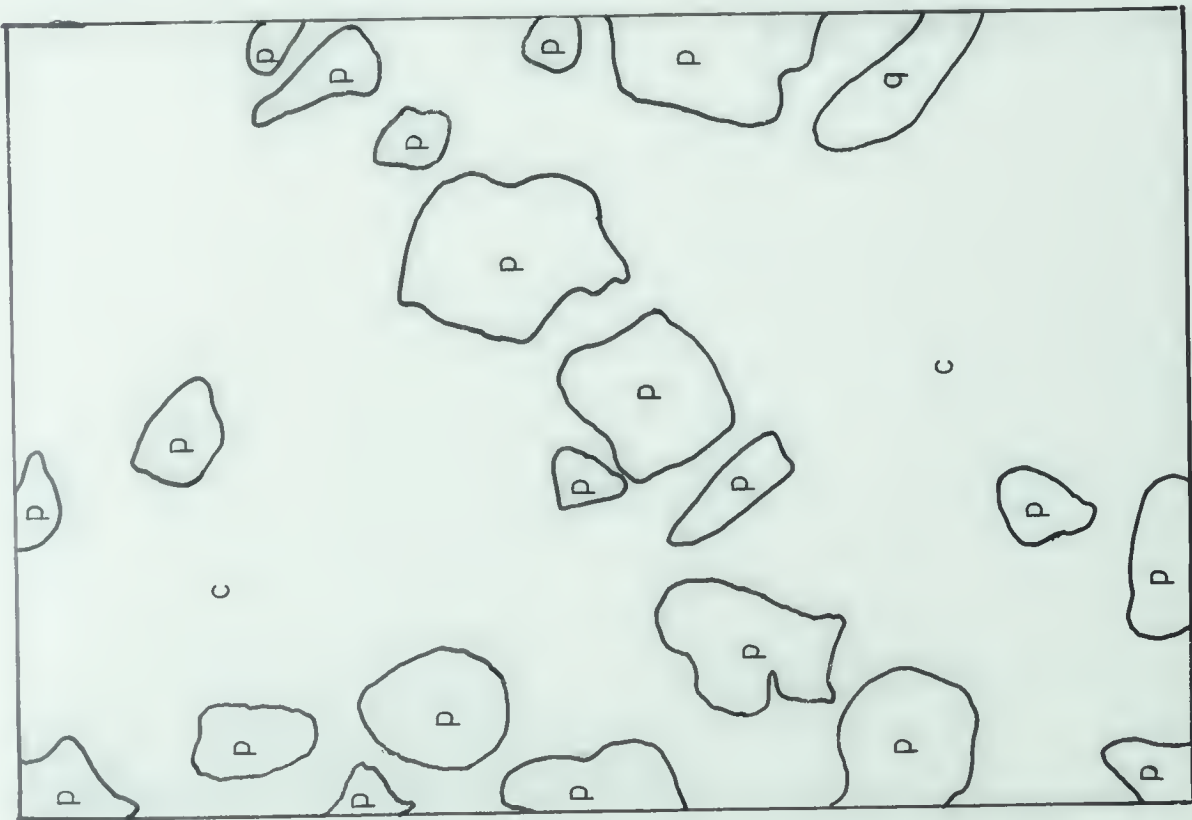
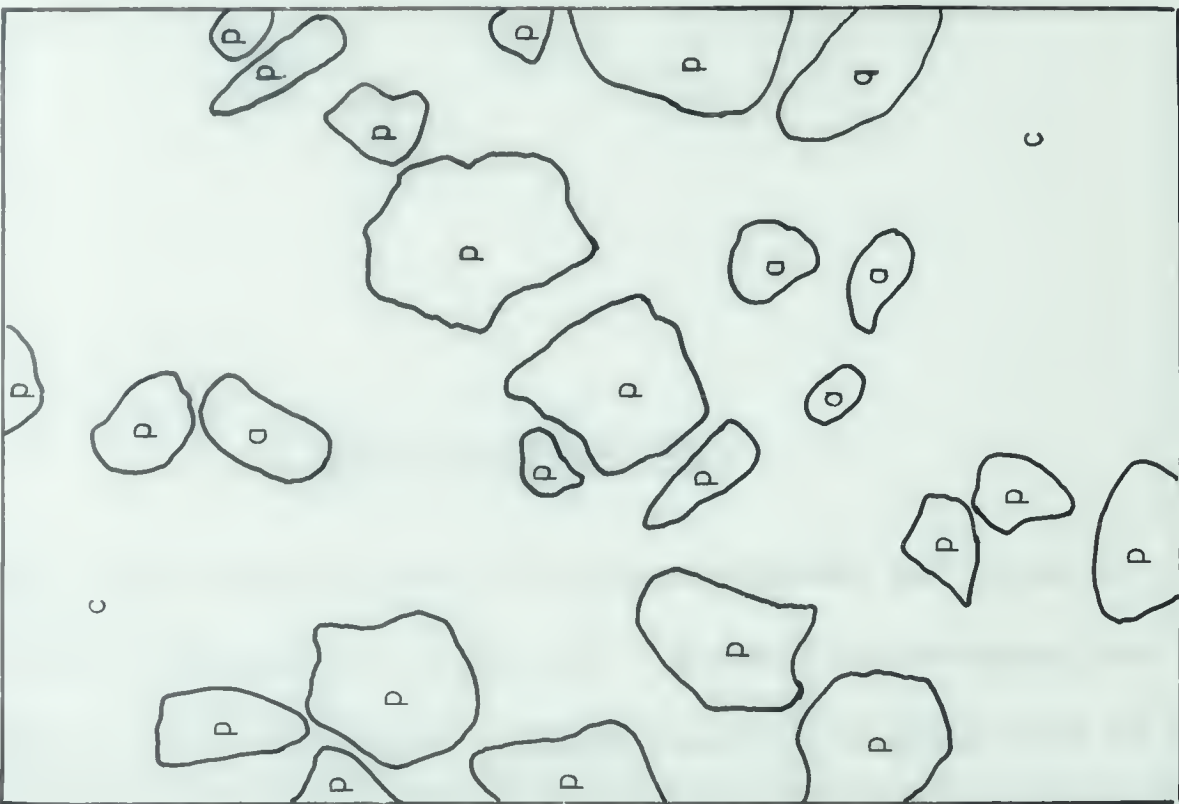


- LEGEND**
- a) Organic-iron concentration
  - b) Large mineral grains



- c) Voids and matrix
- d) Weathered minerals

Schematic Diagram of Plate 2

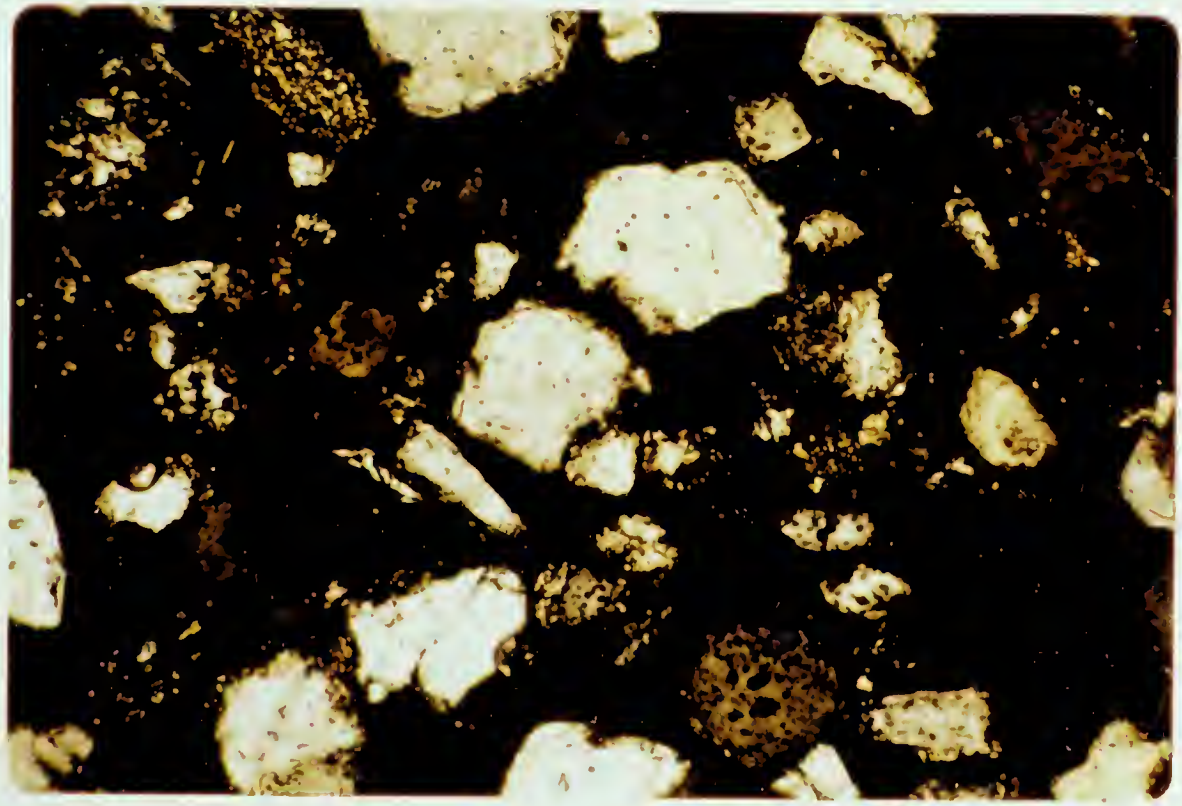


nitrogen  
concentration  
(b)  
nitrogen  
concentration  
(a)

LEGEND  
(a) Nitrogen  
concentration  
(b) Nitrogen  
concentration

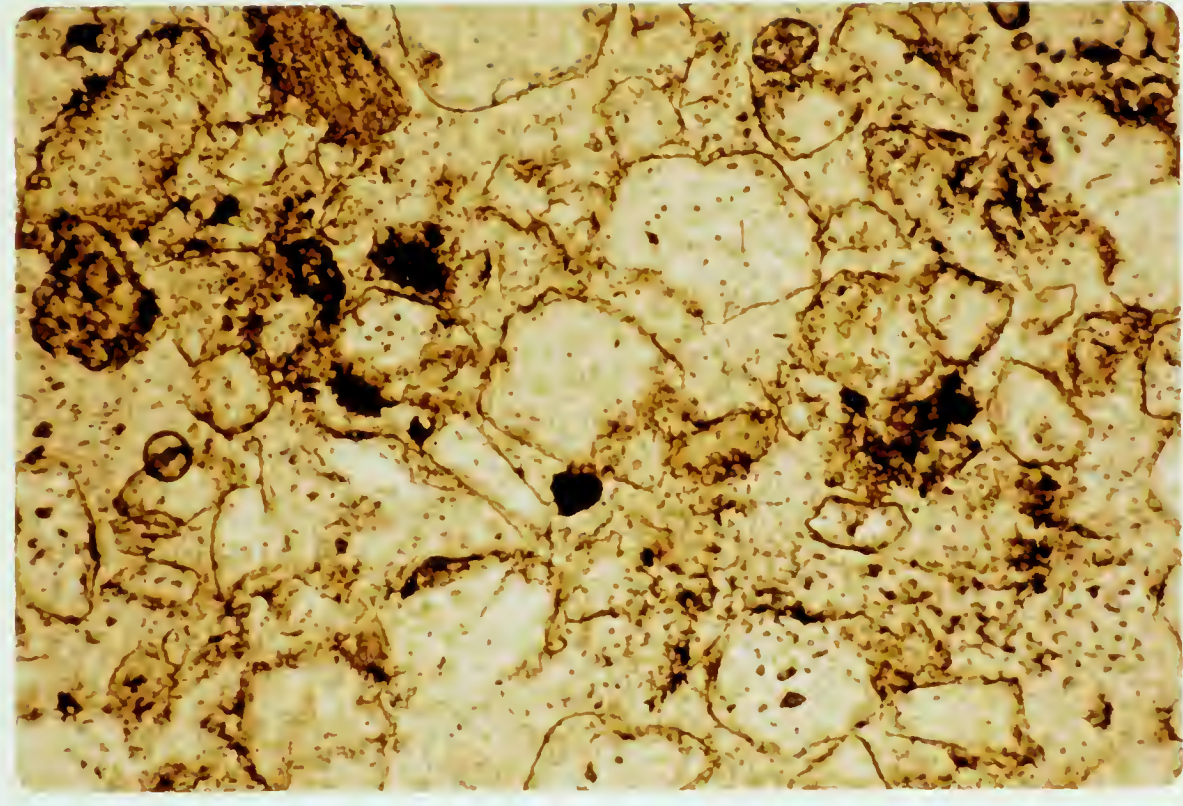


Top of Profile



Crossed Polarizers

Top of Profile



Plane Light



Plate 6. Photomicrograph of the interband material sampled immediately below the top band at Site 2 (vertical).





### Description of Plate 6

Some of the characteristics of the interband material immediately below the top band in the profile at site 2 are depicted by Plate 6. The fabric is similar to that in Plate 4 and thus similar to the granular fabric described by Brewer (1964). The particle size distributions of Plates 4, 5, and 6 are quite similar except for an increase of colloidal material in the intergranular spaces as shown on Plate 5. A comparison of Plates 4, 5, and 6 indicates that the morphological difference between the band and interband materials is evident both macroscopically and microscopically.



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Schematic Diagram of Plate 7

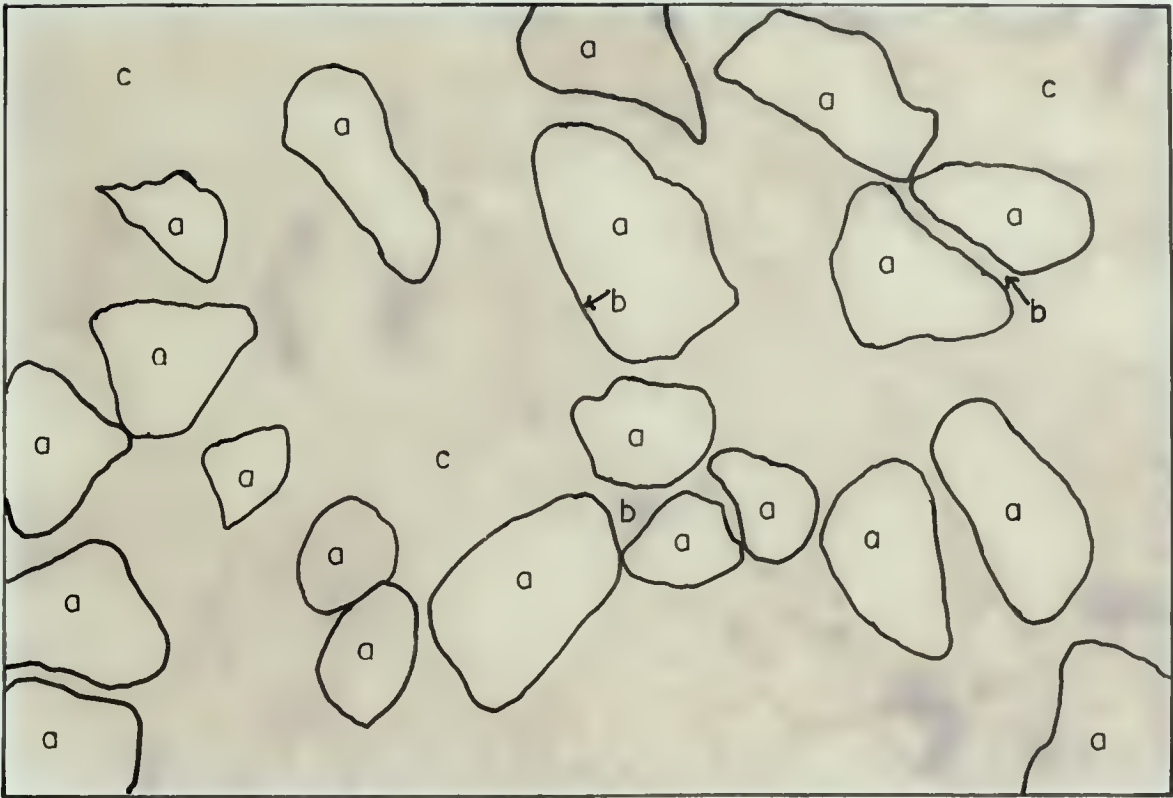
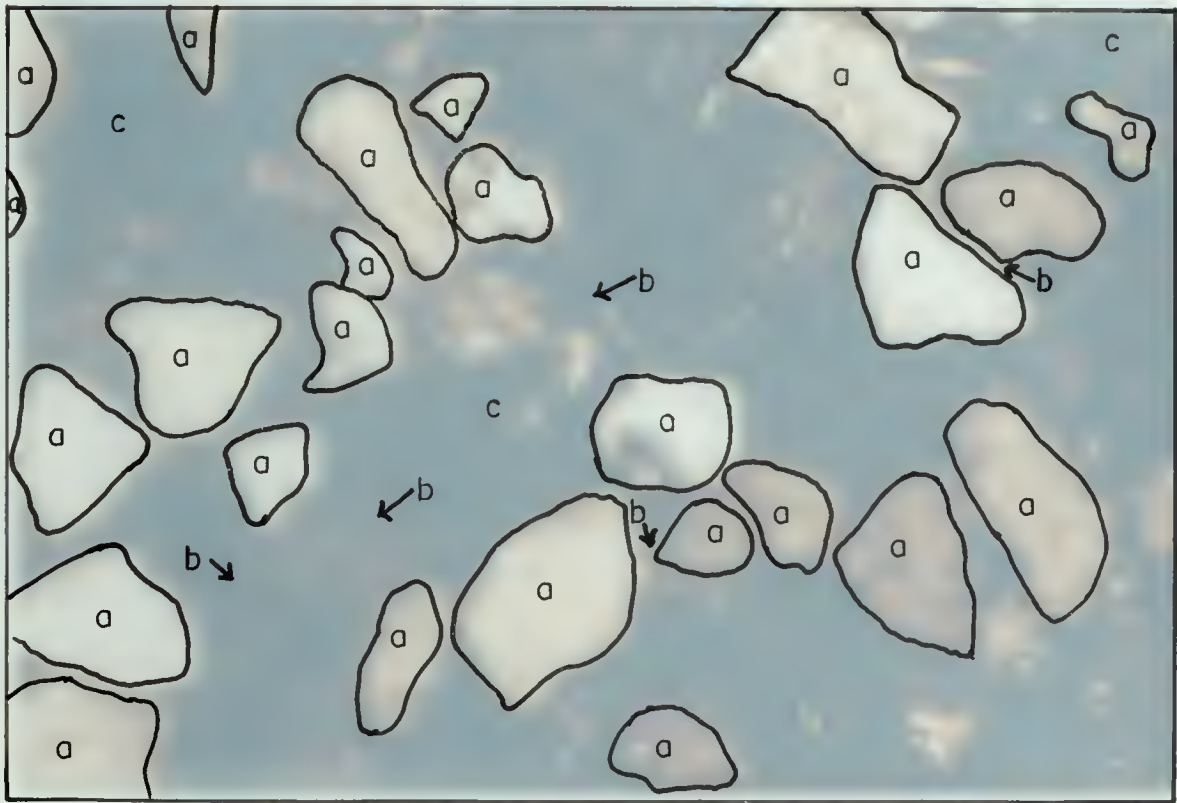


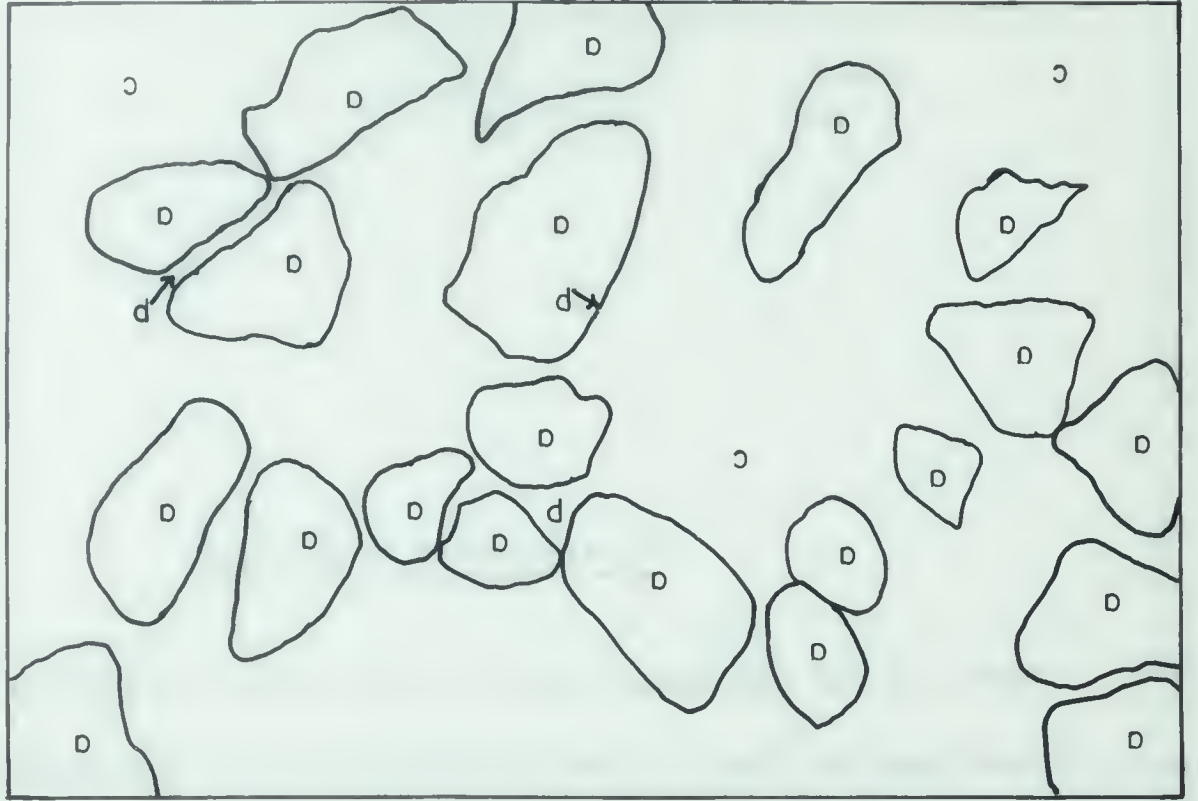
Plate  
Figure

- LEGEND
- a) Large mineral grains
  - b) Grain coatings
  - c) Voids and matrix

1.0 cm

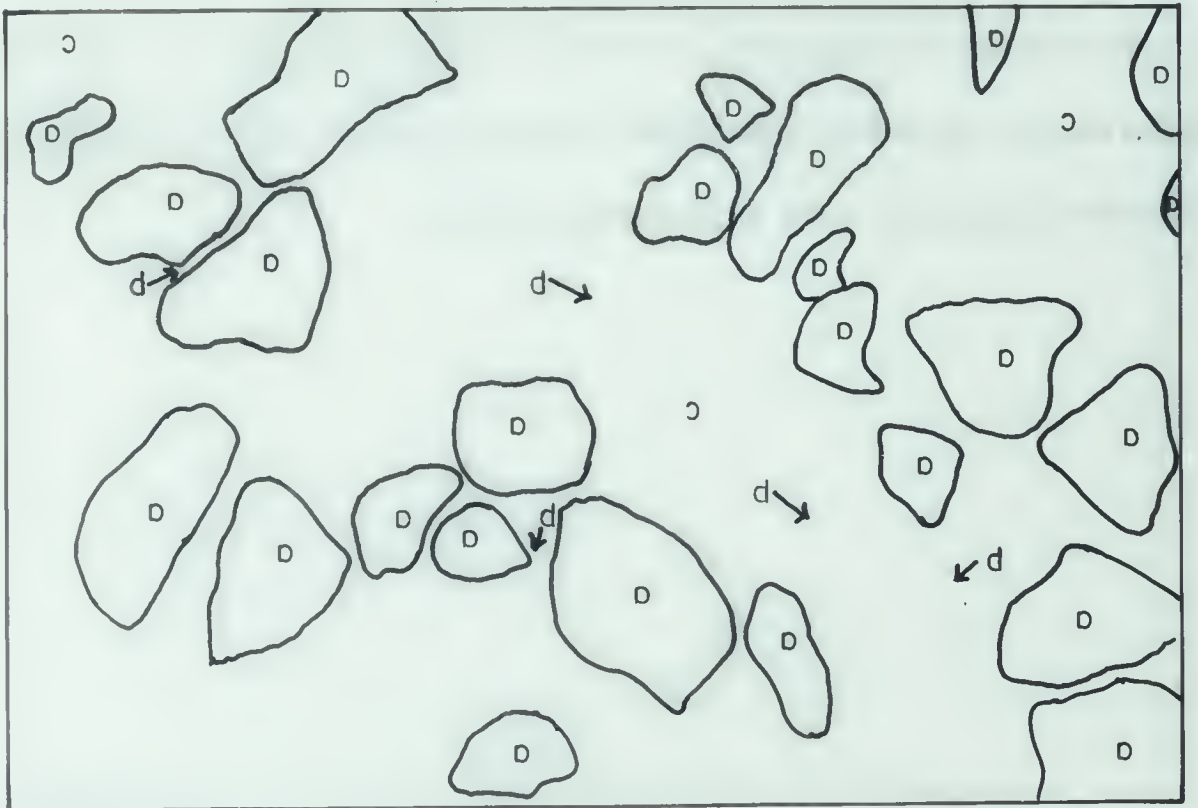


Continued  
Figure

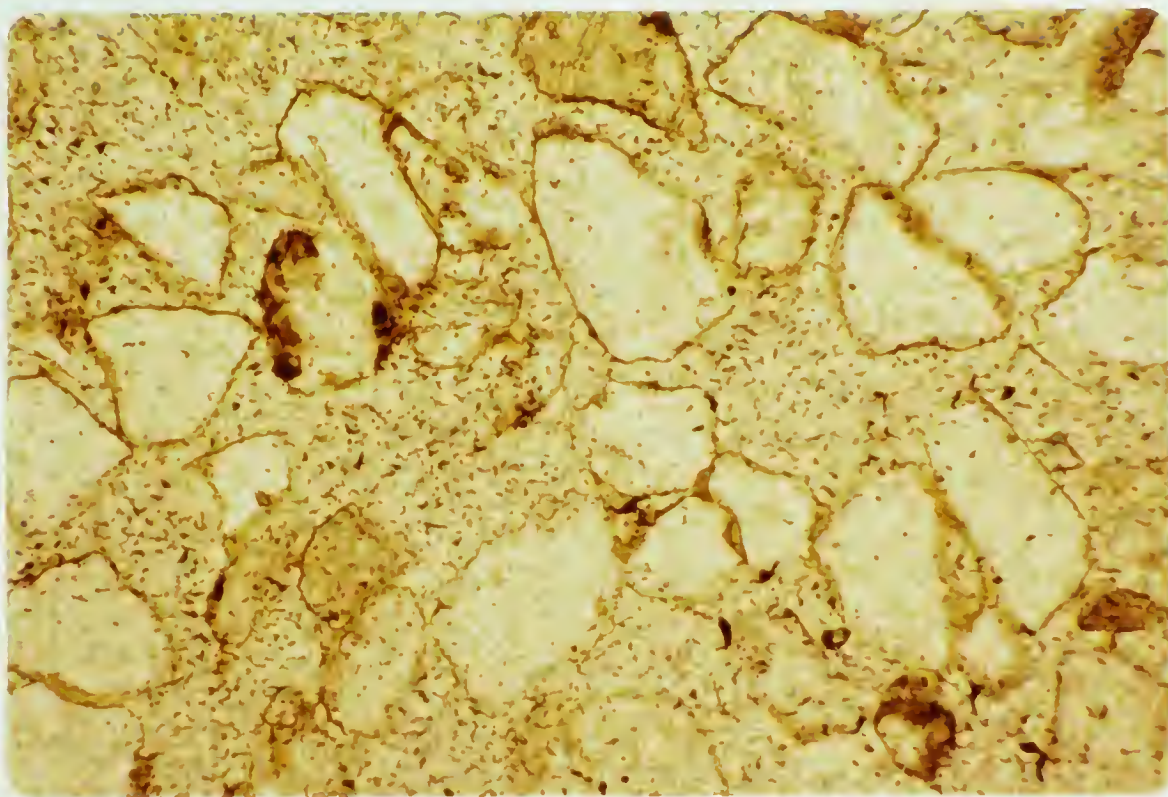


LEGEND

- a) Large mineral grains
- b) Grain coatings
- c) Voids and matrix

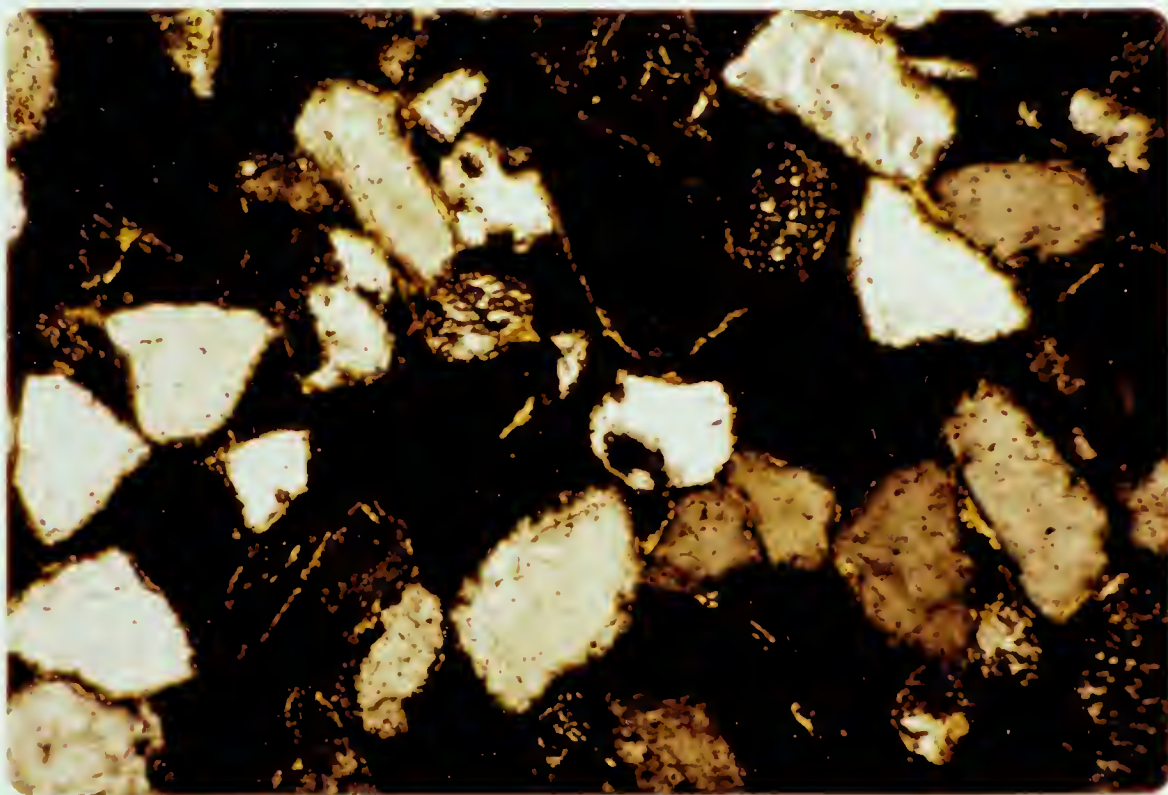






Plane  
Light

← 1.0 mm. →



Crossed  
Polarizers

Plate 7. Photomicrograph of bottom band, sampled at Site 2 (horizontal).



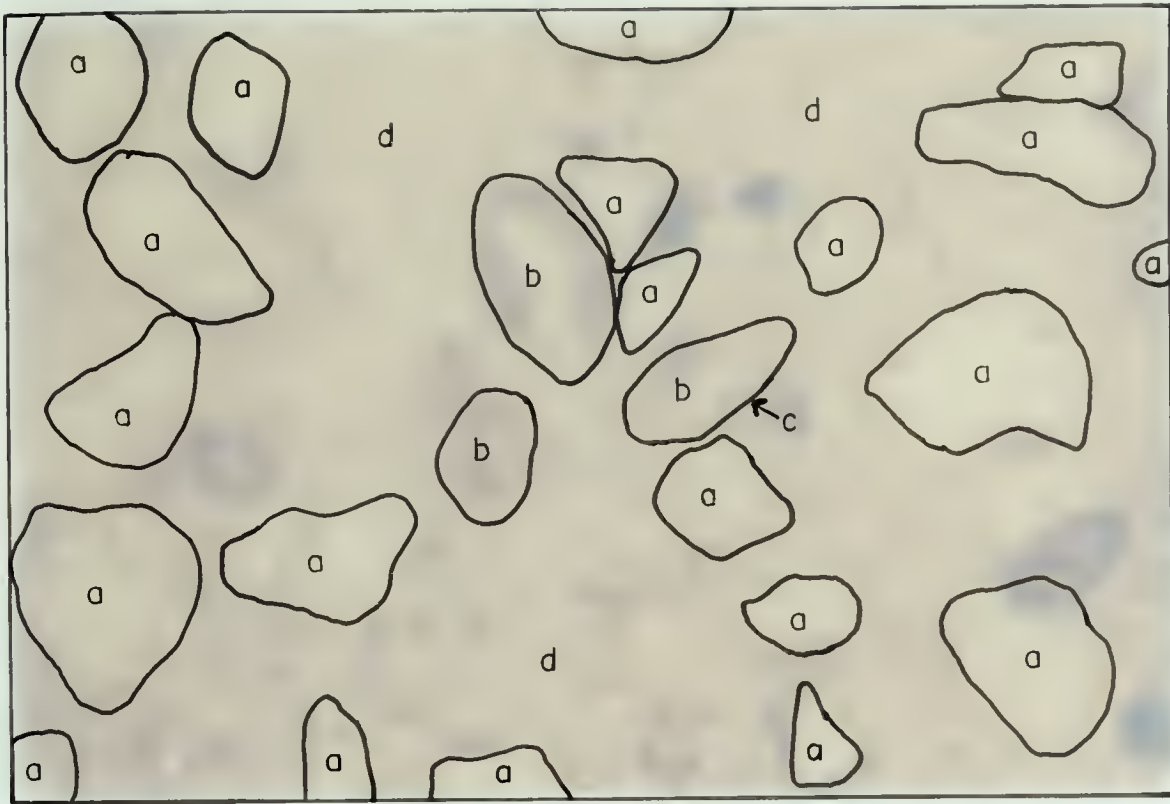
### Description of Plate 7

Some of the characteristics of the bottom band in the profile at site 2 are depicted by Plate 7. The fabric is similar to Plate 4 and Plate 6 and thus similar to the granular fabric described by Brewer (1964). The particle size distribution is similar to that shown on Plates 4 to 8. In plane light there is evidence of coatings on many of the grains. In cross polarized light only a few coatings of oriented clays are evident. Much of the coating material is isomorphous and thus is likely organic matter or amorphous iron. The bottom band has fewer coatings than the top band at site 2. However, there are more coatings in the bottom band (Plate 7) than in the "Ae-like" material (Plate 4) or in the interband material (Plate 6).





# Schematic Diagram of Plate 8



## LEGEND

- a) Large mineral grains
- b) Weathered minerals
- c) Grain coatings
- d) Voids and matrix

1.0 mm

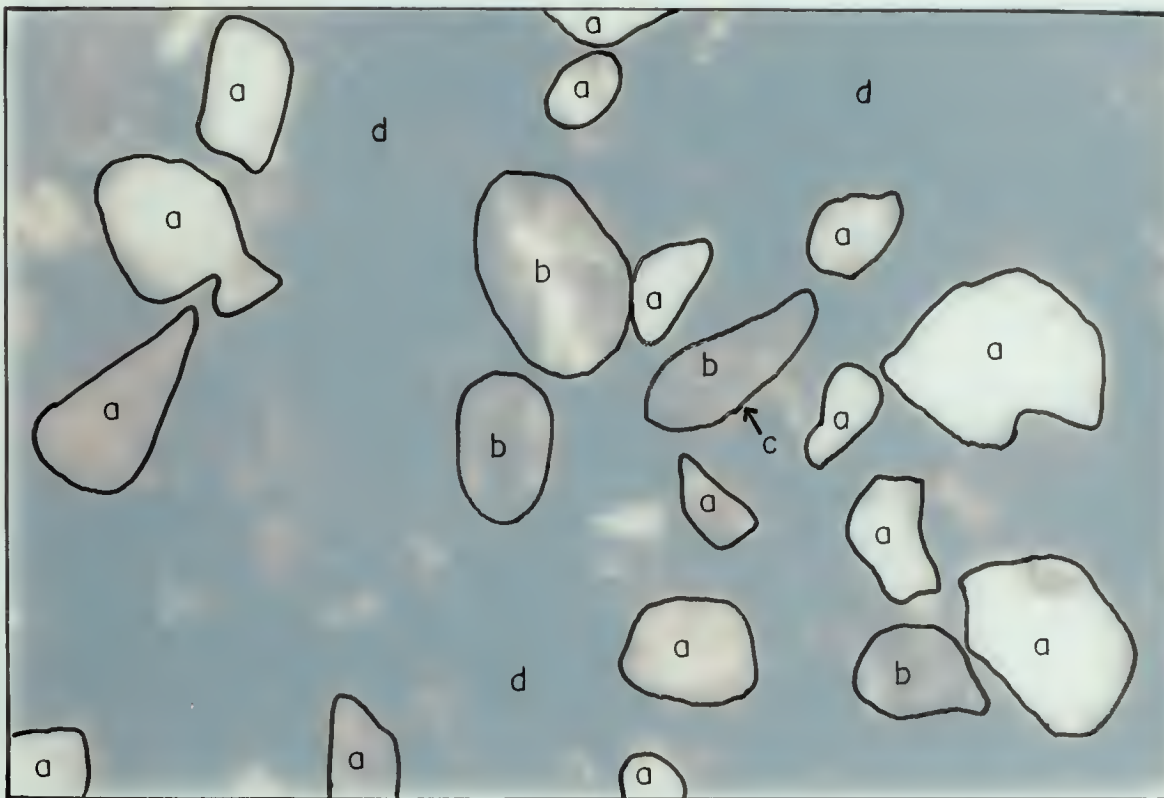
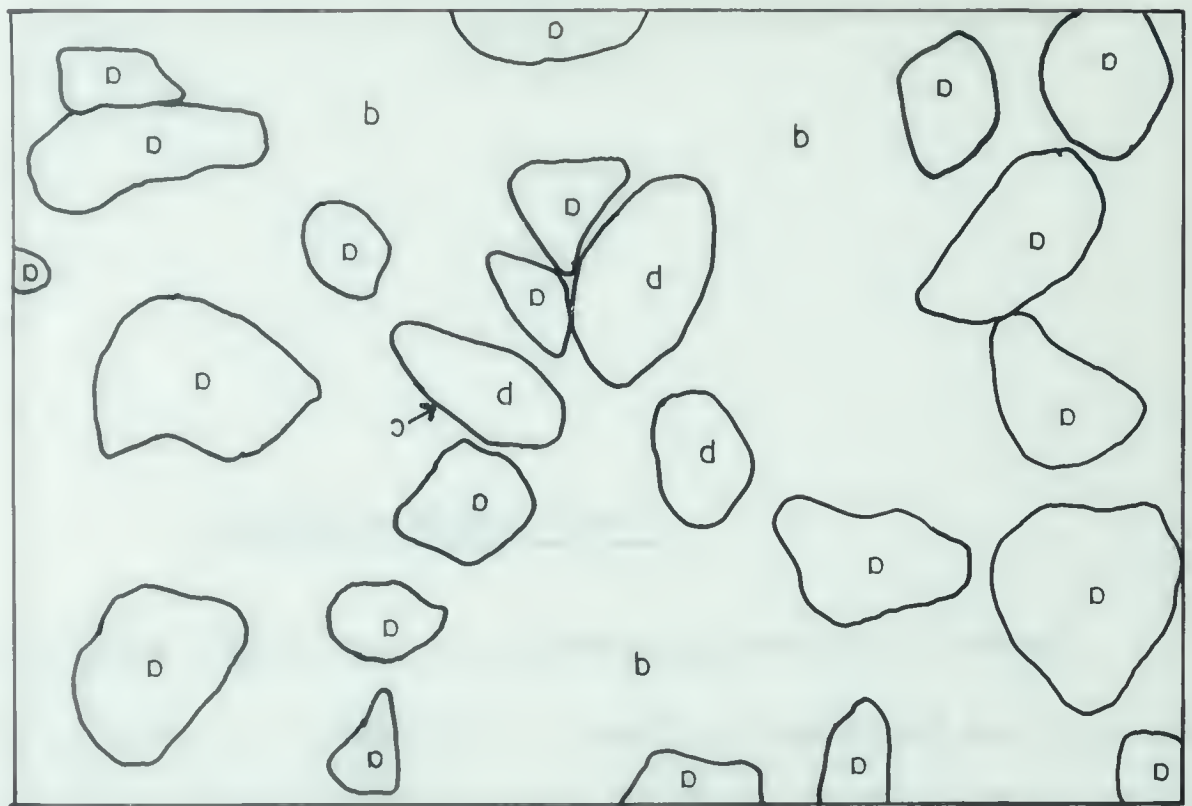


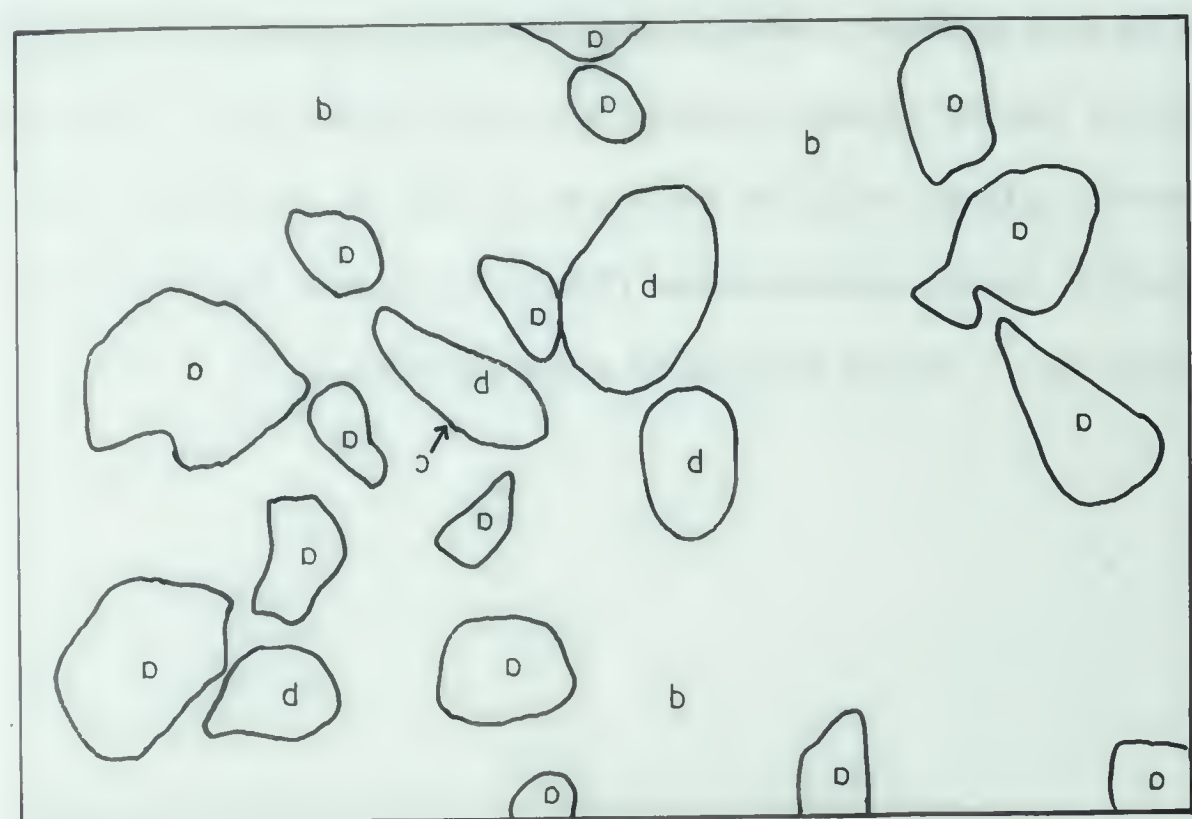
Fig. 8. Photomicrograph of the mineral material from the sample 8405, Sample 41, Site 2 (horizontal).

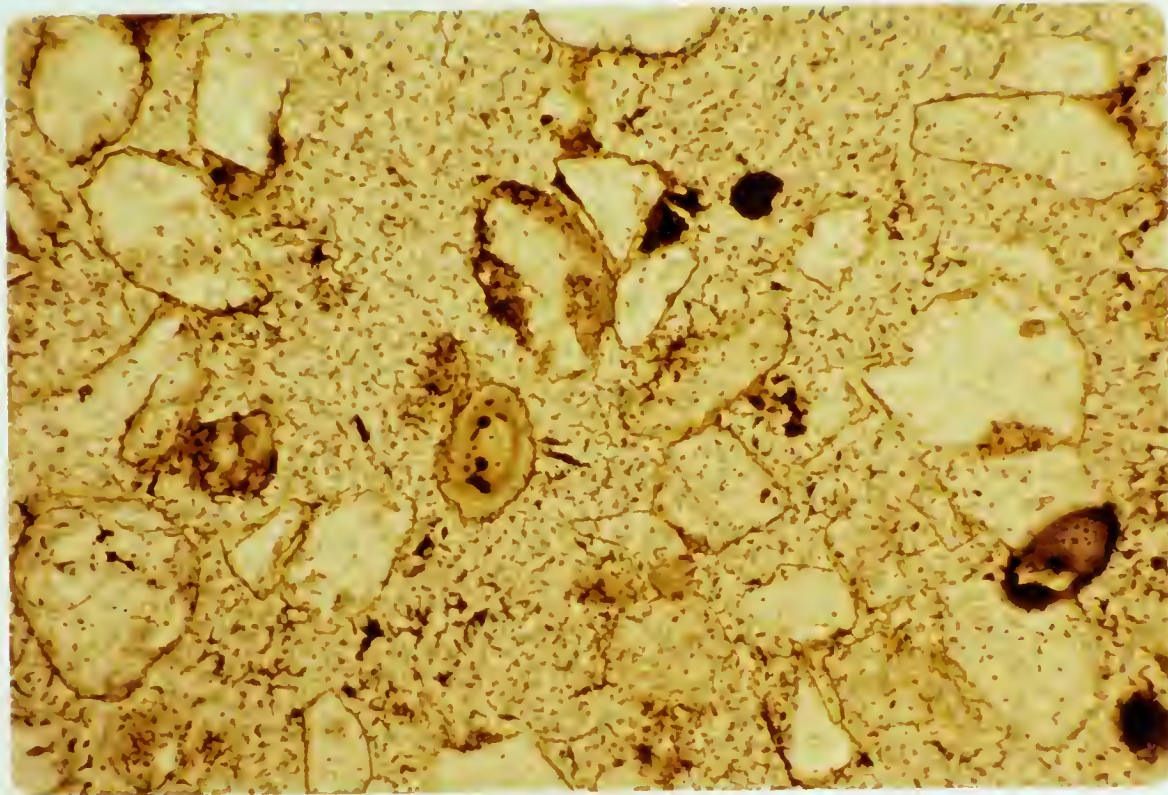


Schematic Diagram of Plate 8



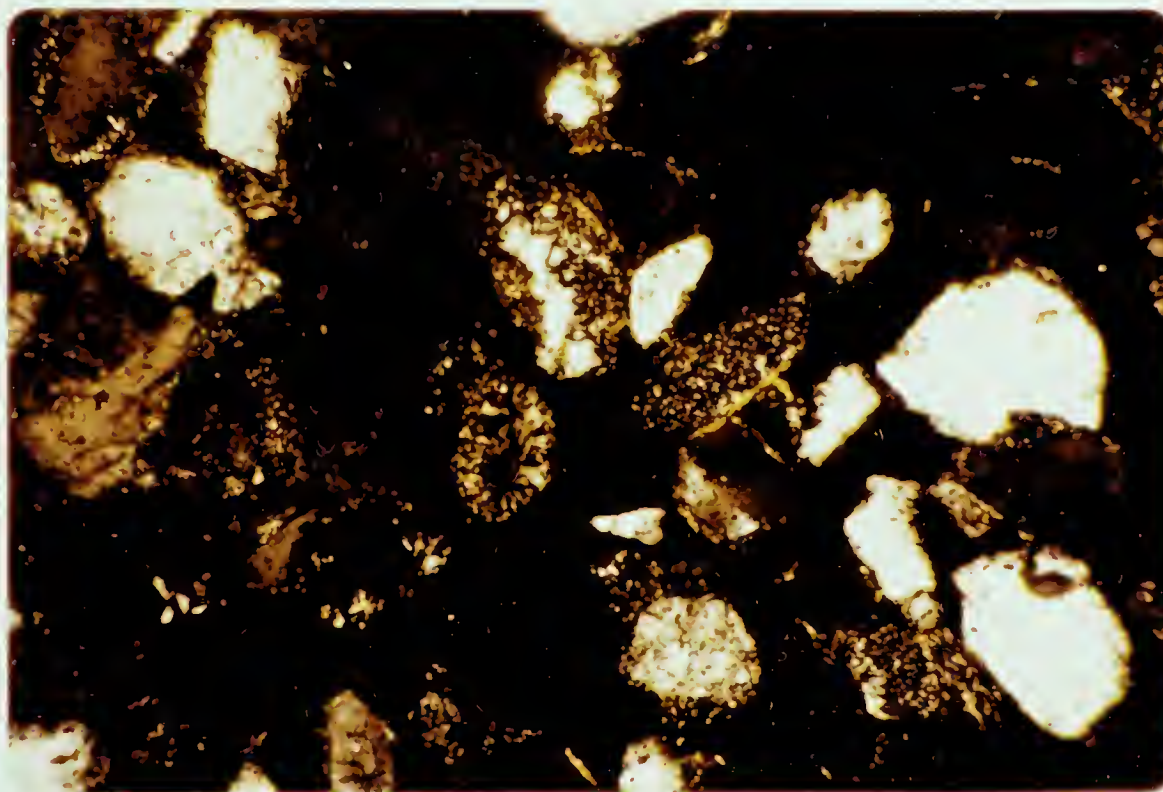
- LEGEND
- (a) Large mineral grains
  - (b) Weathered minerals
  - (c) Grain coatings
  - (d) Voids and matrix





Plane  
Light

← 1.0 mm. →



Crossed  
Polarizers

Plate 8. Photomicrograph of the interband material below the bottom band, sampled at Site 2 (horizontal).



Description of Plate 8

Some of the characteristics of the interband material below the bottom band in the profile at site 2 are depicted by Plate 8. The fabric is again granular (Brewer, 1964). There is less evidence of coatings on the mineral grains shown on Plate 8 than on Plate 7. The Plates 4 to 8 indicate that the particle size distribution does not vary greatly within this profile. The top band at site 2 appears to have more accumulated colloids than the bottom band, but the bands have greater accumulations than the interbands.







Schematic Diagram of Plate 9



Transmitted  
light

LEGEND

- a) Iron - clay  
concentration
- b) Large mineral  
grains
- c) Plasma-matrix,  
voids and small  
mineral grains

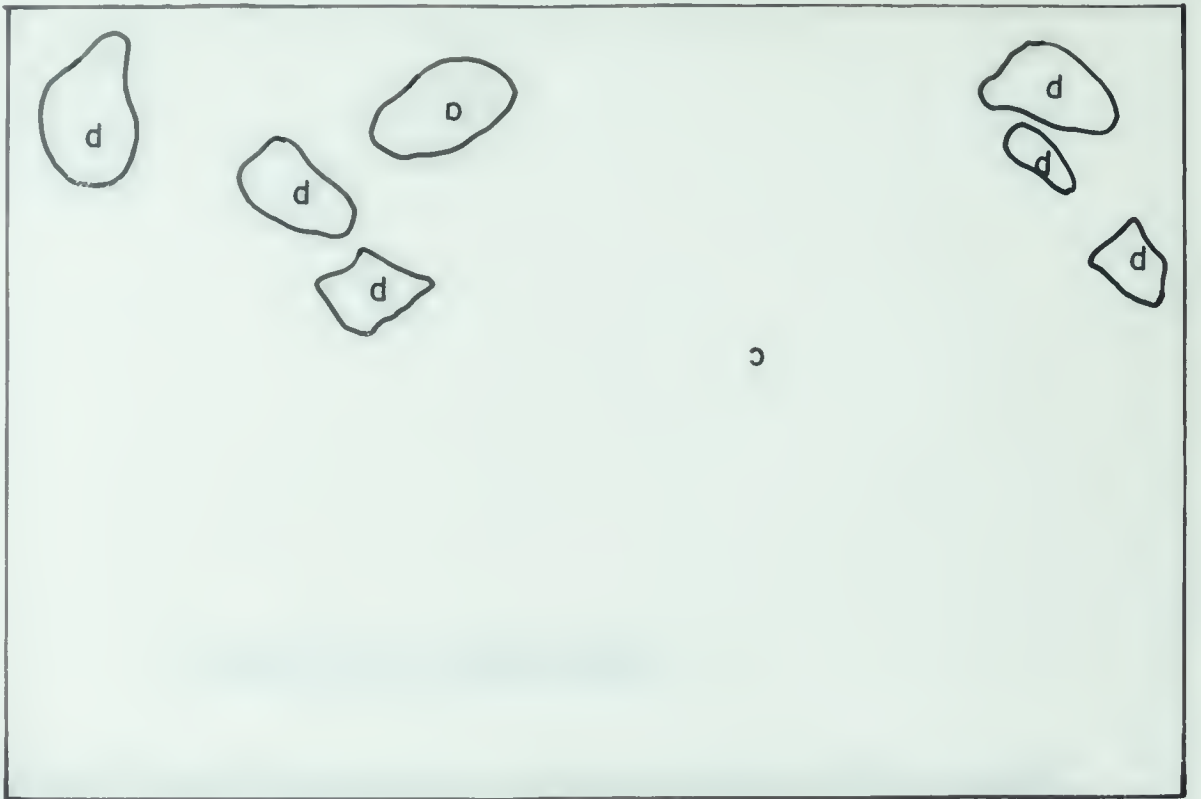
1.0 mm.



crossed  
polarizers

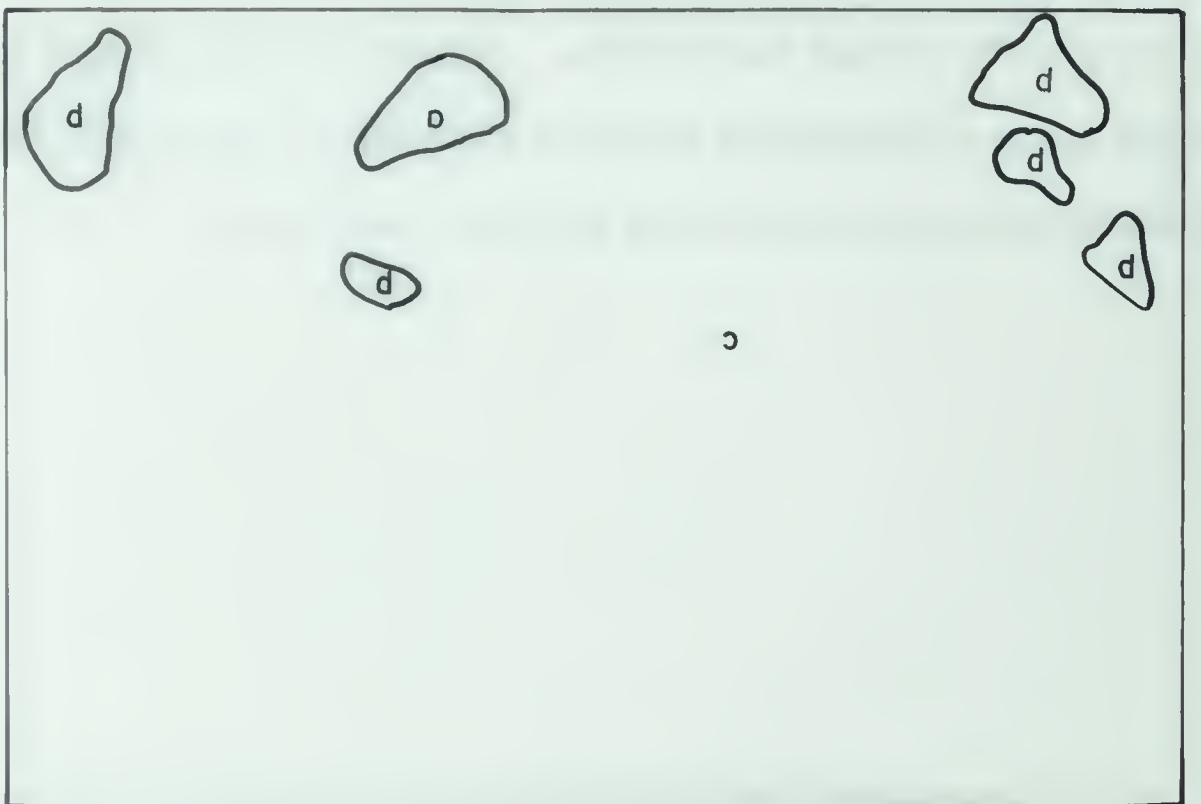
Figure 1. Micrograph of the top band, sampled at Site 1.

Schematic Diagram of Plate 2

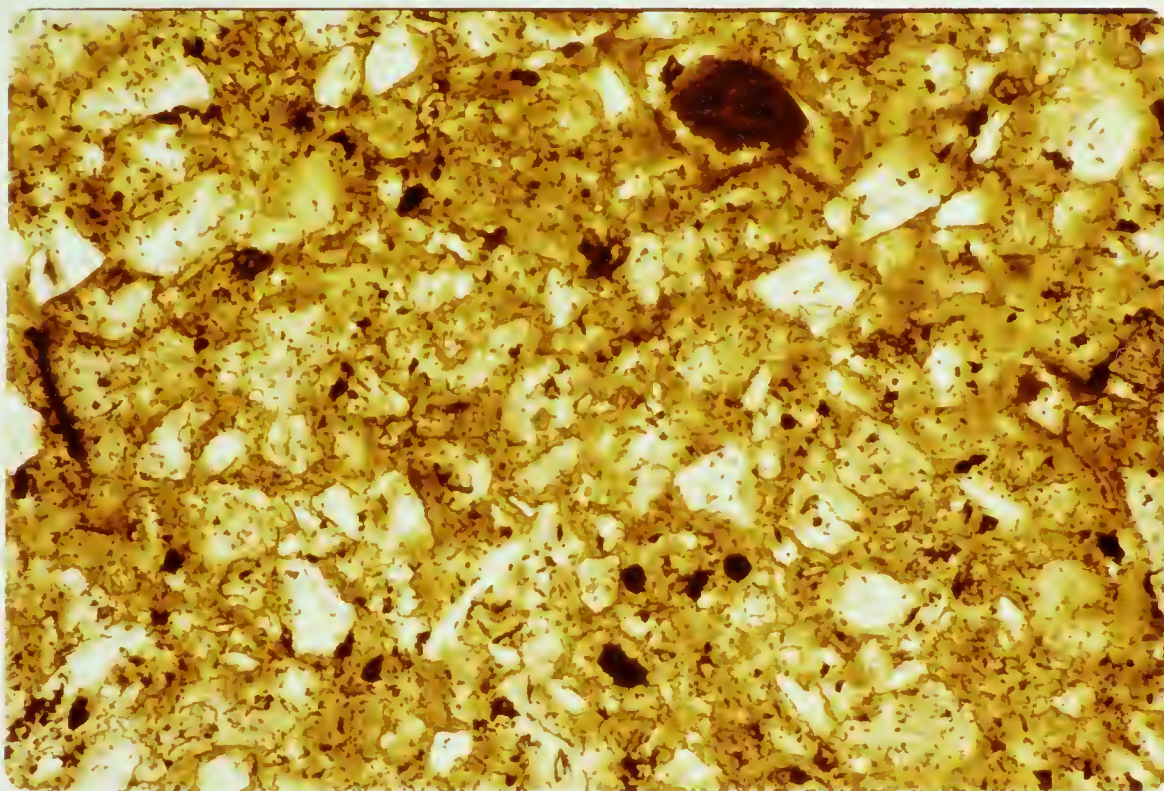


LEGEND

- a) Iron - clay concentration
- b) Large mineral grains
- c) Plasma-matrix, voids and small mineral grains

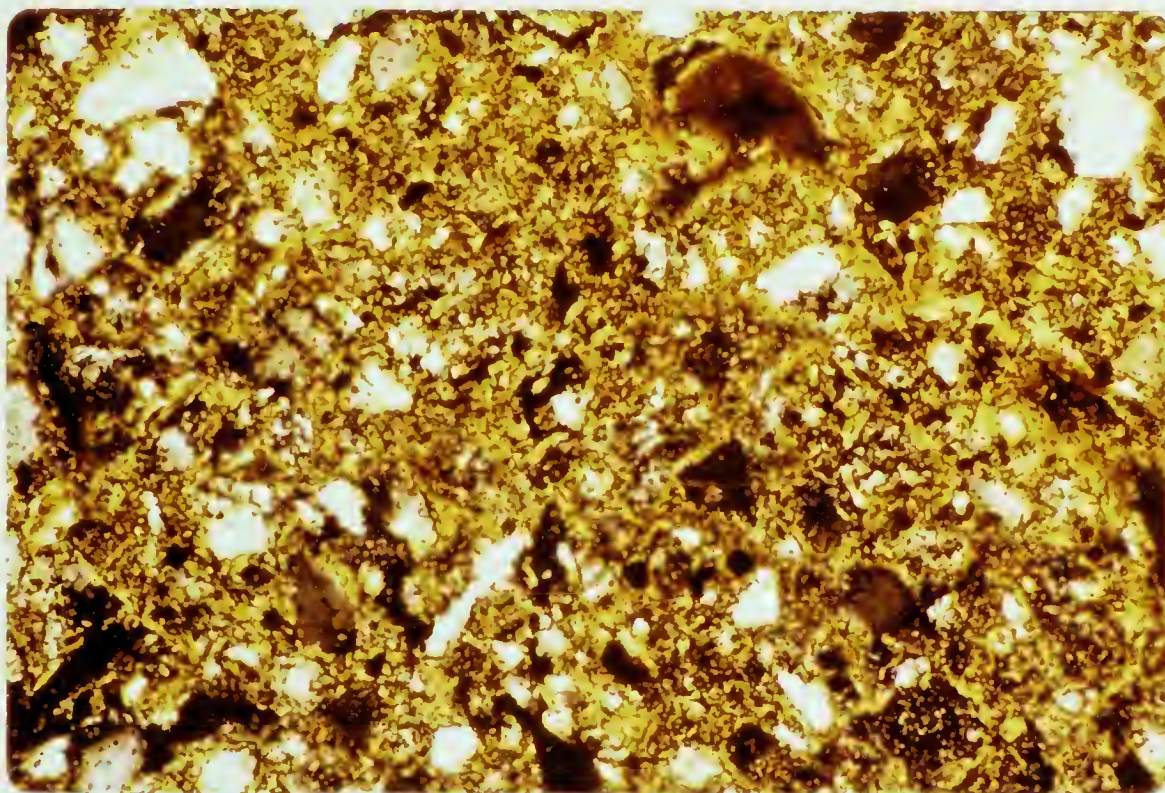






Plane  
Light

← 1.0 mm. →



Crossed  
Polarizers

Plate 9. Photomicrograph of the top band, sampled at Site 3 (horizontal).





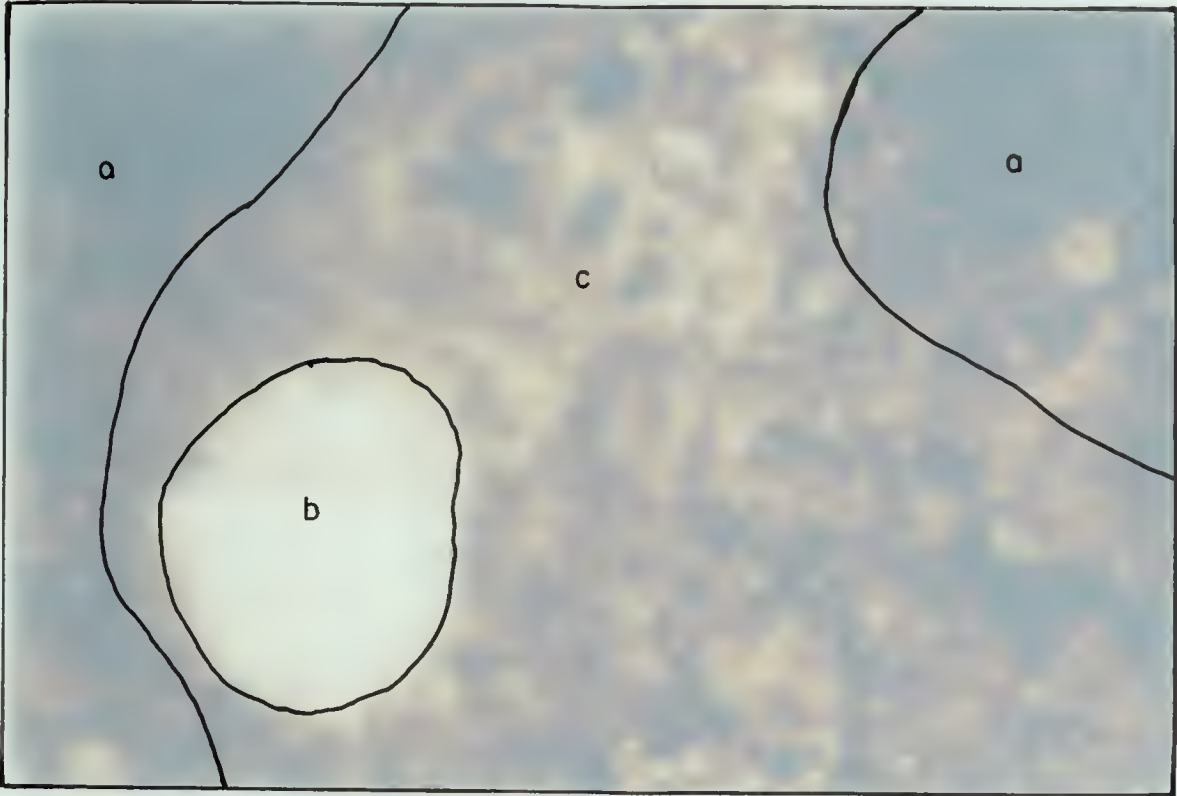
Description of Plate 9

Some of the characteristics of the top band in the profile at site 3 are depicted by Plate 9. The fabric is similar to the porphyroscopic fabric as described by Brewer (1964). The particle size distribution of this material is finer than that in site 2 (Plates 4 to 8). The mineral grains have much more fine material adjacent to them than do the mineral grains in site 2 (Plates 4 to 8). There is a considerable amount of iron accumulated in the band as shown by plane light. Some oriented clay is also present as indicated by viewing under crossed polarizers. The interband materials in the profiles at site 3 have considerably less accumulated colloids than do the band materials. The fabric of the interband materials in site 3 is similar to the intertextic fabric described by Brewer (1964).





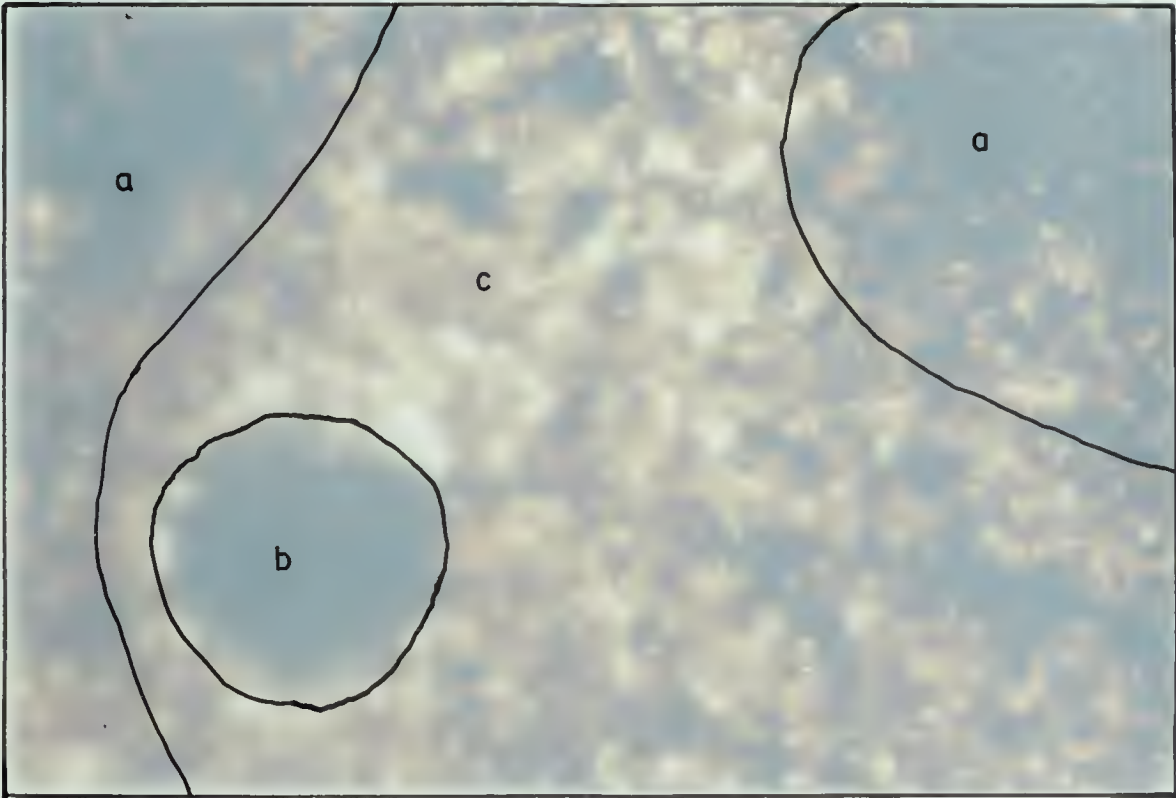
Schematic Diagram of Plate 10



Plane  
Light

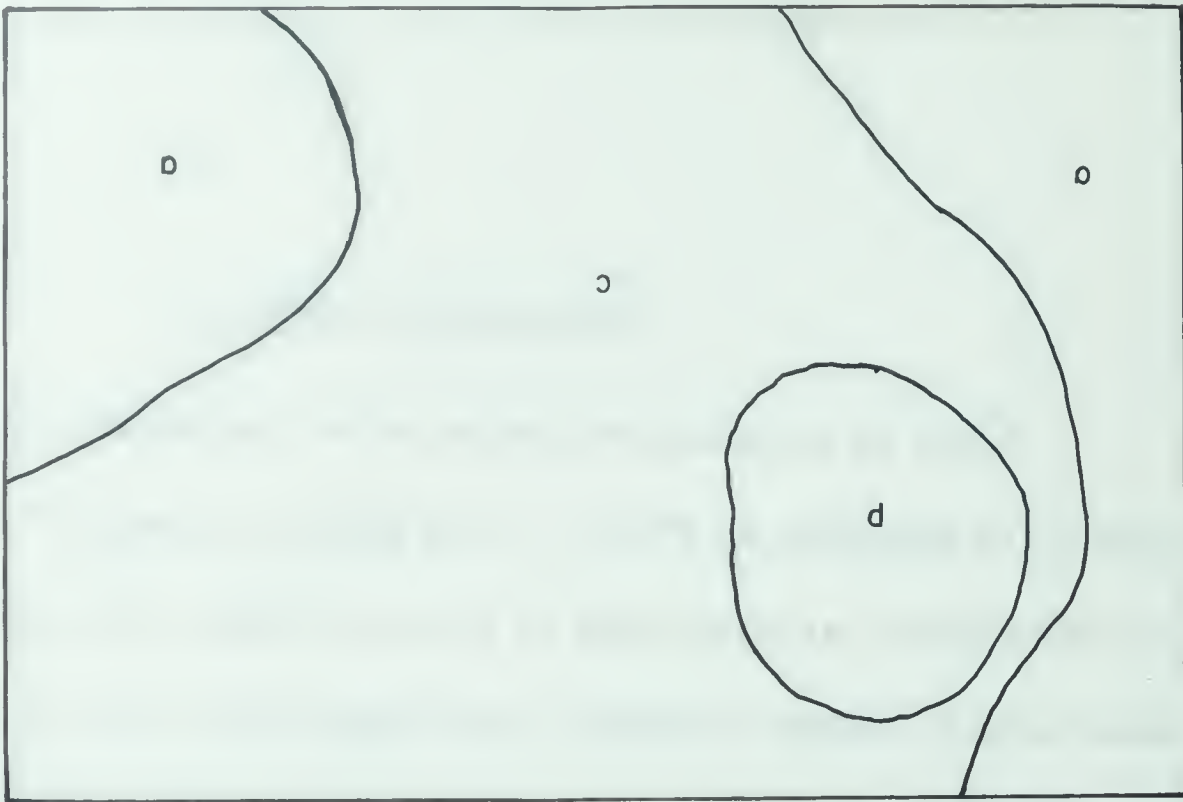
- LEGEND
- a) Organic matter-iron concentration
  - b) Void
  - c) Plasma-matrix, small voids and mineral grains

1.0 cm

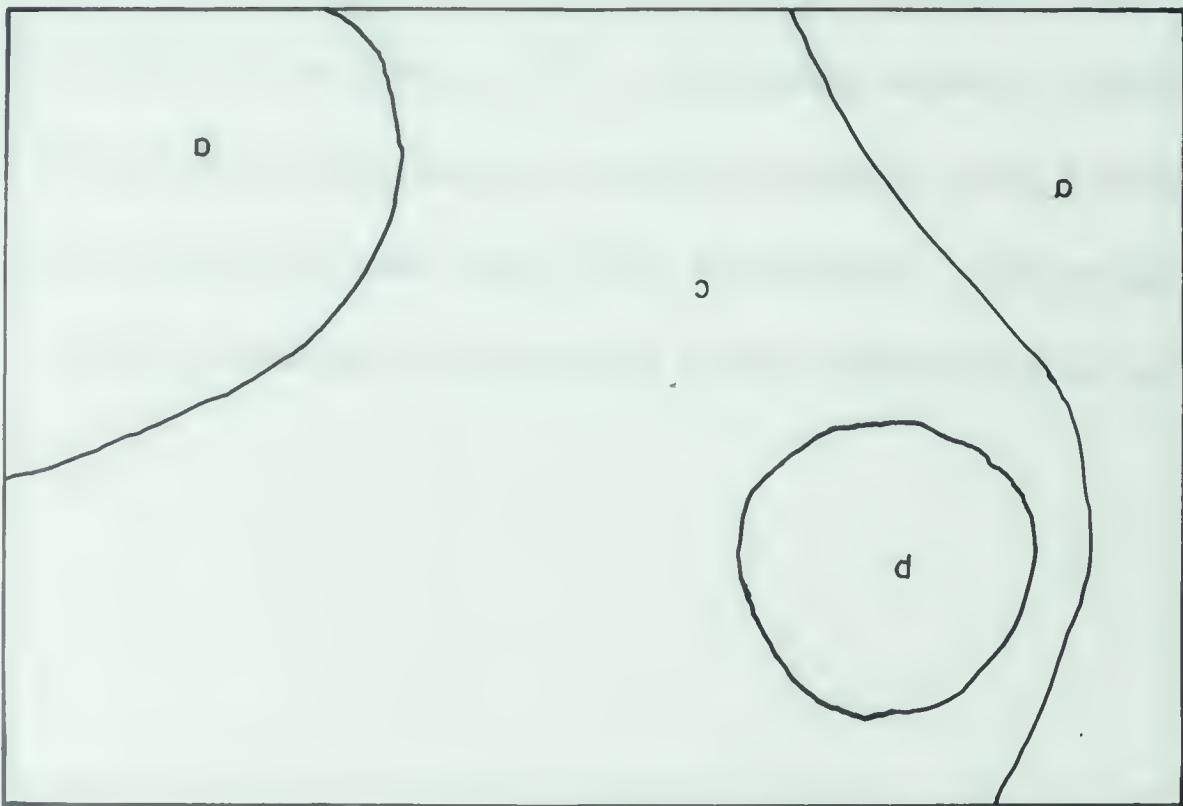


Crossed  
Polarizers

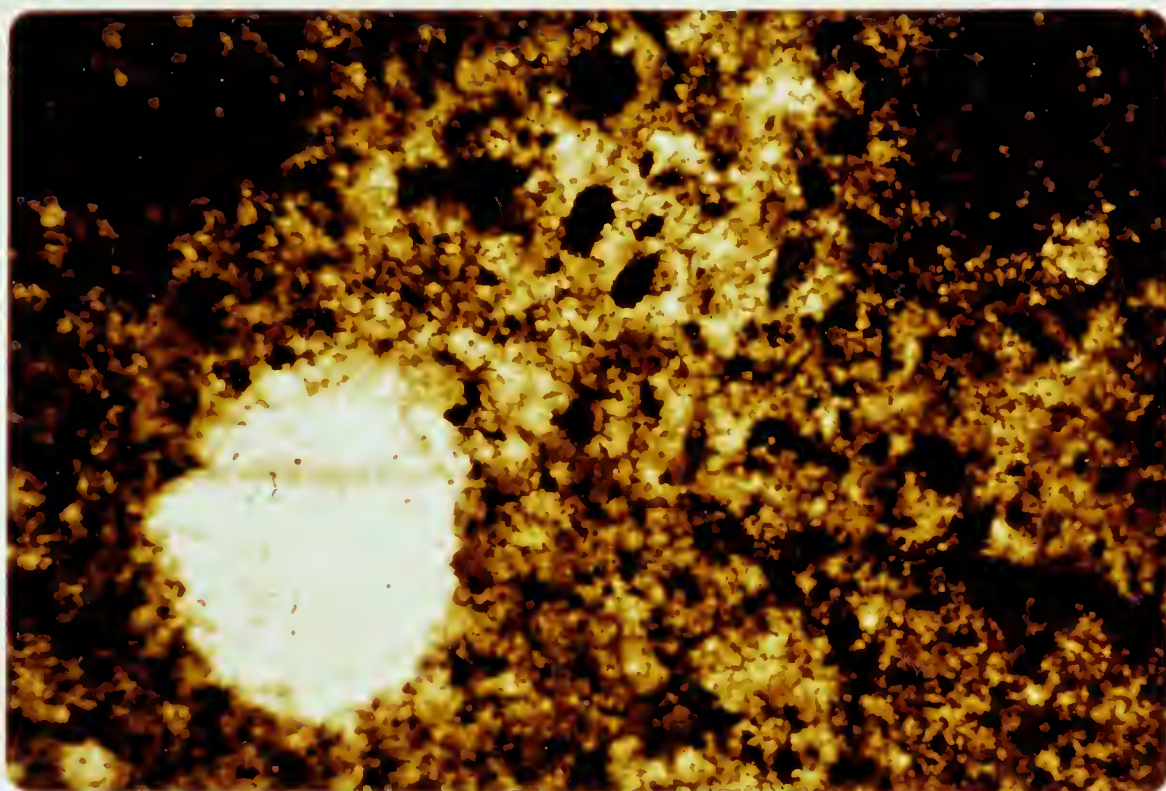
Micrograph of the bottom band, sampled at  
Site 1 (horizontal).



- LEGEND
- a) Organic matter-ion concentration
  - b) Void
  - c) Plasma-matrix, small voids and mineral grains

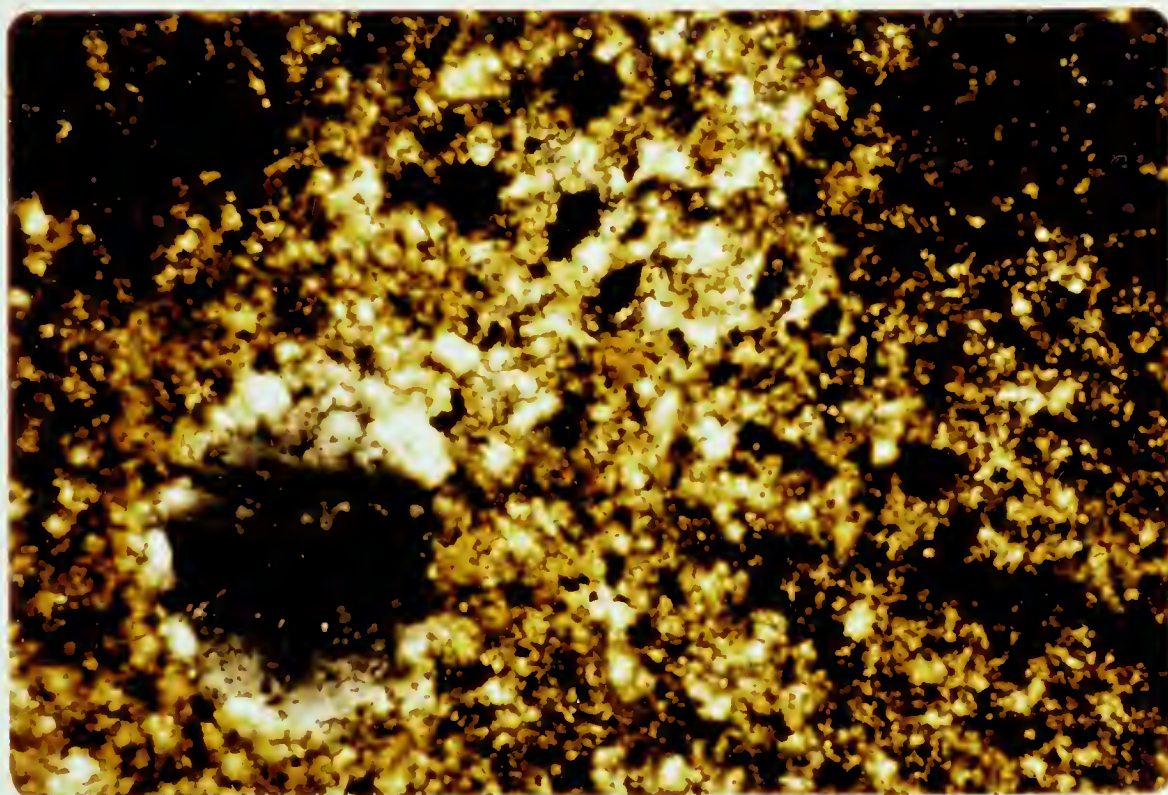






Plane  
Light

← 1.0 mm. →



Crossed  
Polarizers

Plate 10. Photomicrograph of the bottom band, sampled at Site 3 (horizontal).



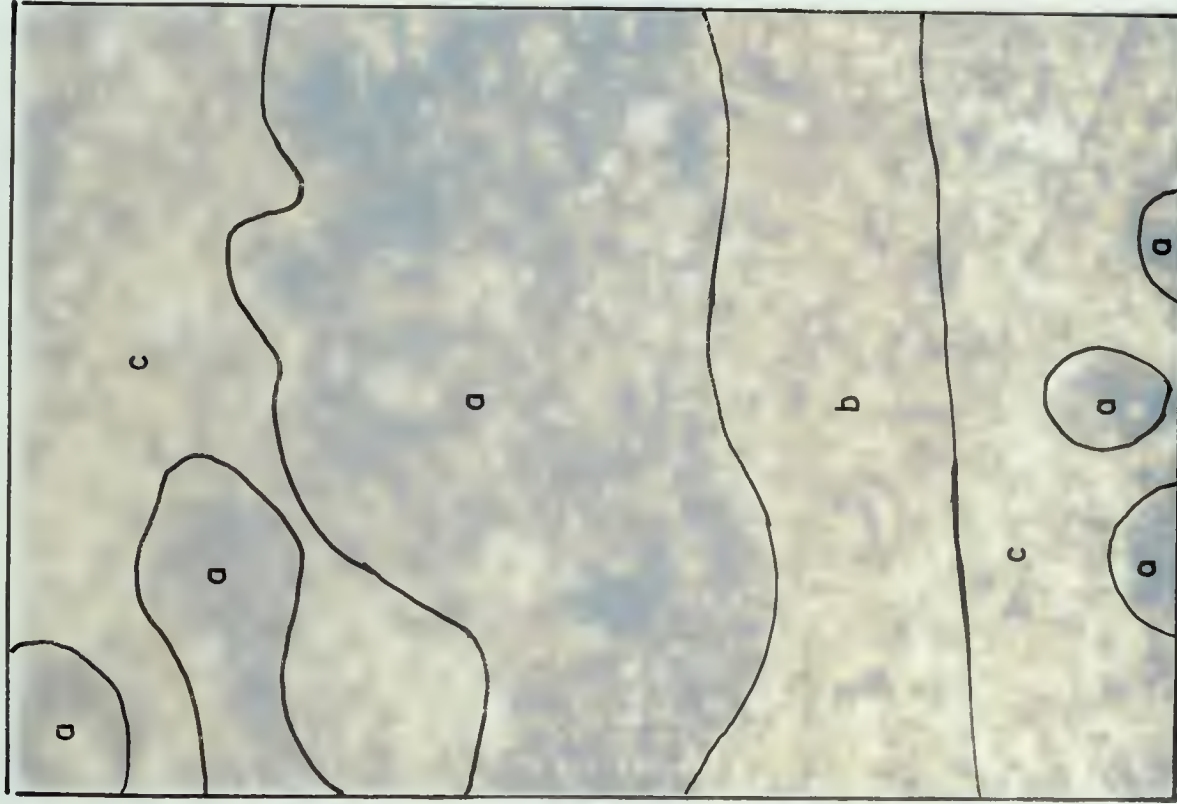


Description of Plate 10

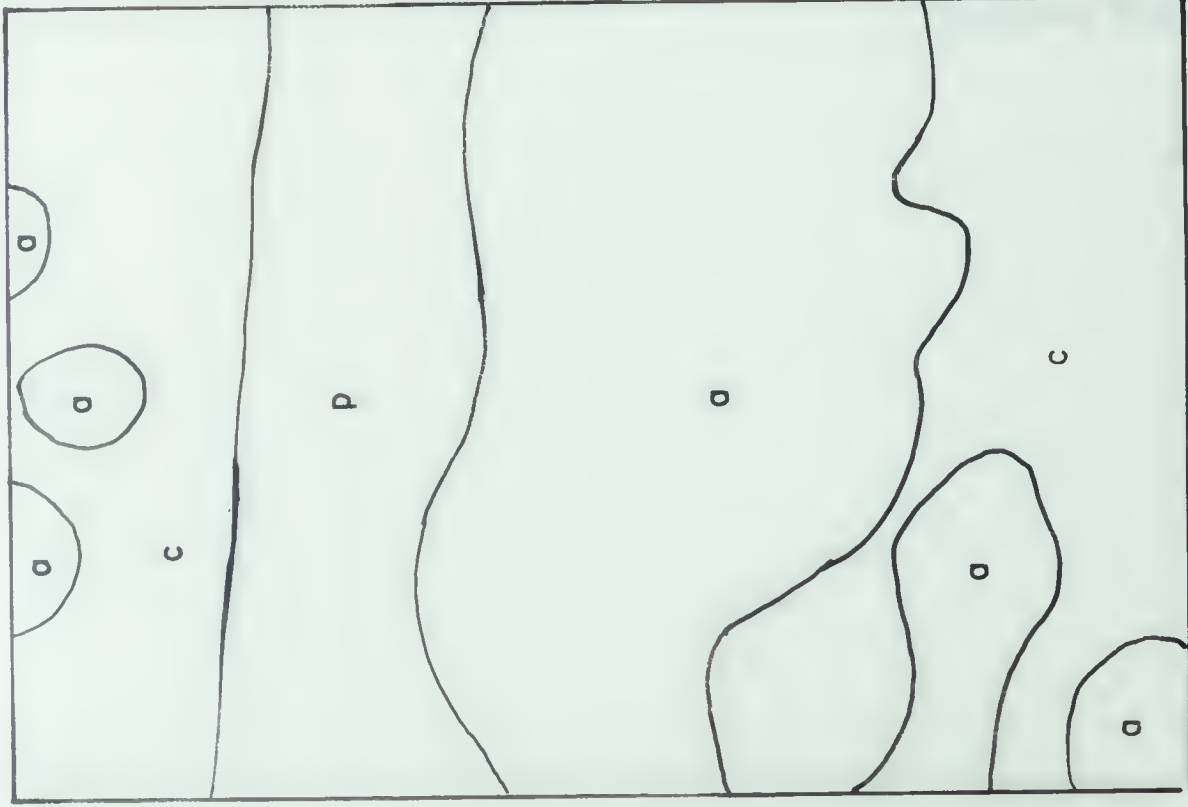
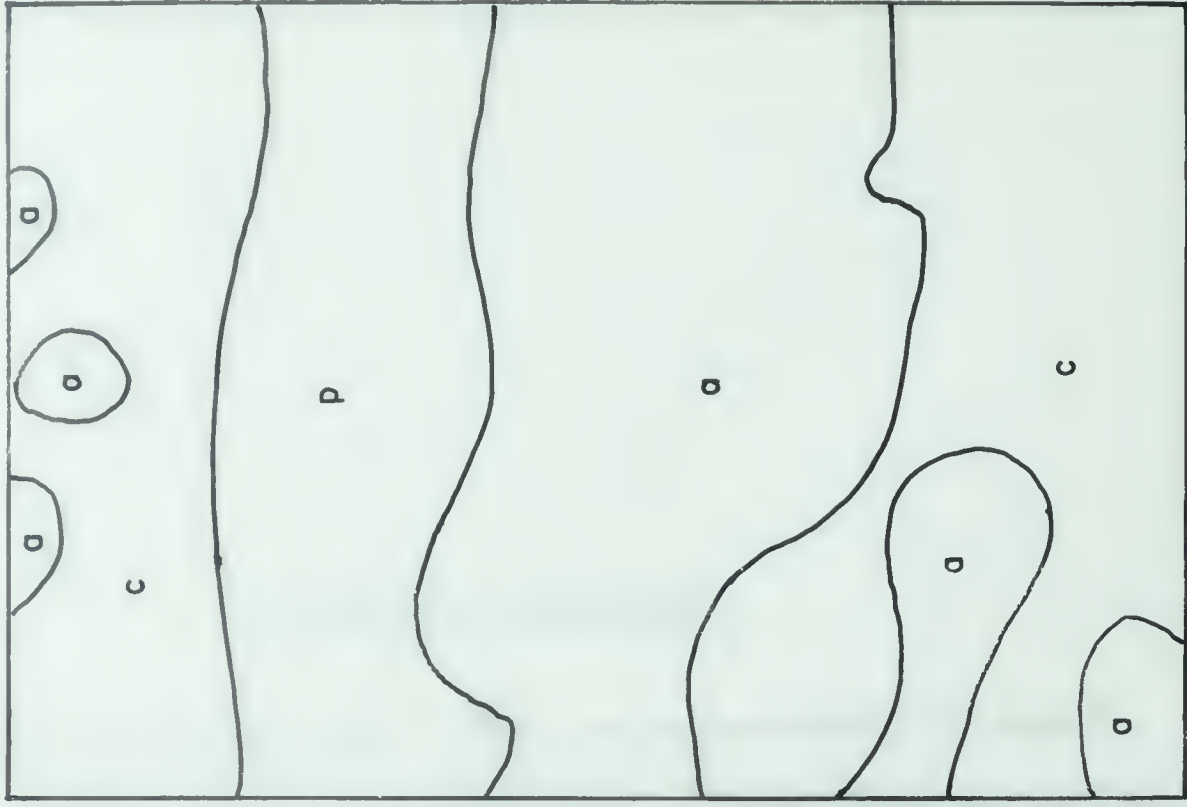
Plate 10 illustrates some of the characteristics of the bottom band in the profile at site 3. The fabric is similar to the porphyro-skelic fabric as described by Brewer (1964). There is a considerable amount of isotropic material evident which appears to be largely organic matter and possibly includes amorphous iron, in this band. The uniformity and clean circumference of the void suggests a worm or root channel.



# Schematic Diagram of Plate 11



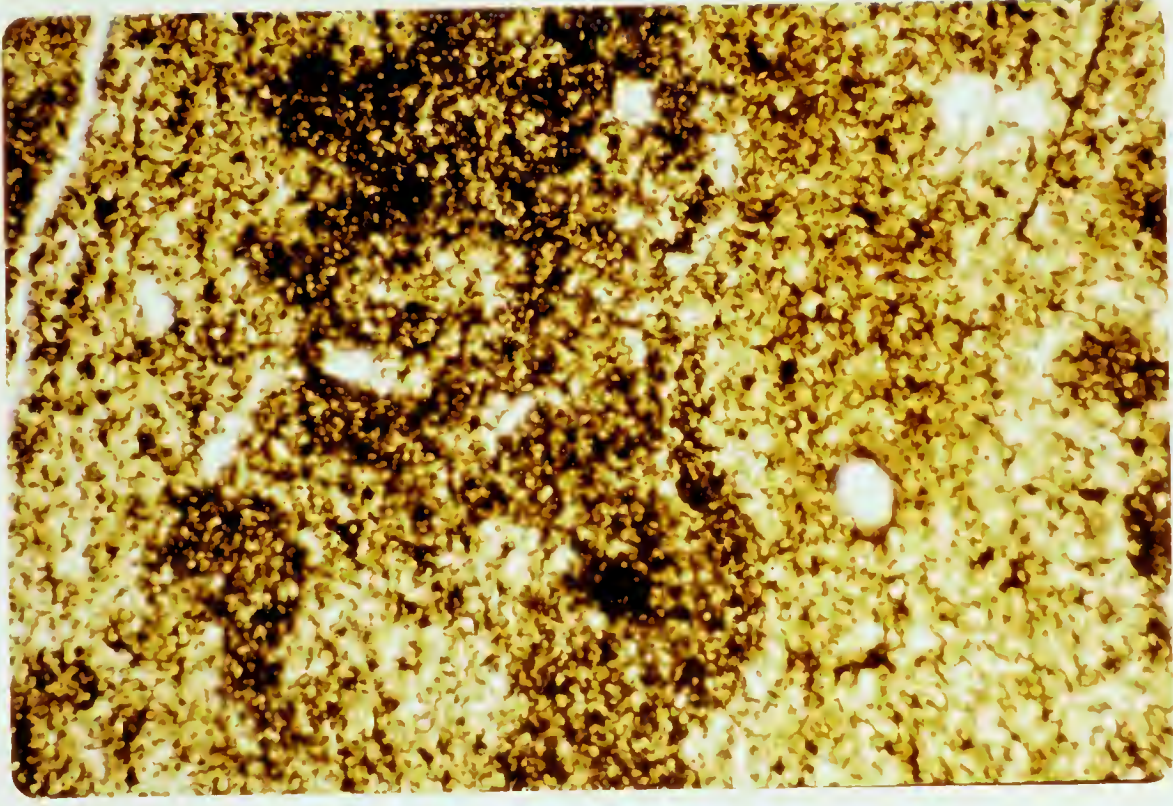
- LEGEND**
- a) Greyish-brown region
  - b) Reddish region
  - c) Matrix region



LEGEND  
a) Greyish-brown region  
b) Reddish region  
c) Matrix region

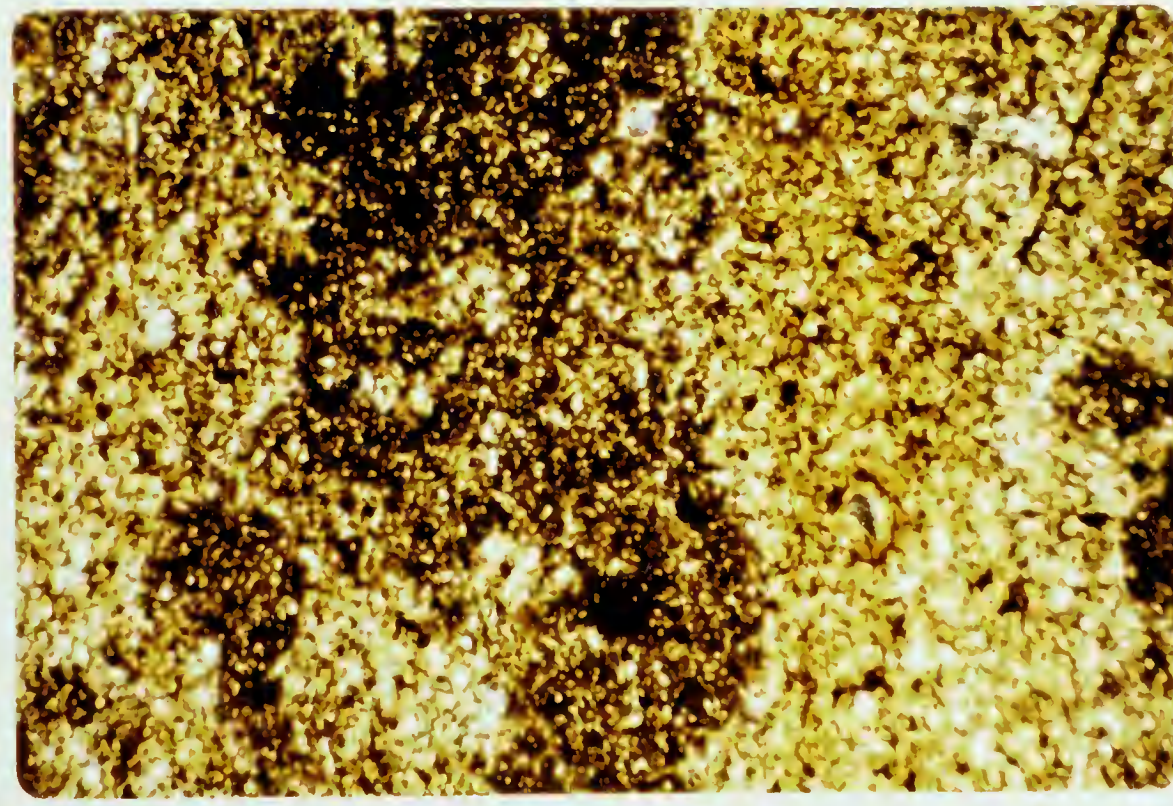


Top of Profile



Plane Light

Top of Profile



Crossed Polarizers

3.3 mm.

Plate 11. Photomicrograph of the bottom band, sampled at Site 3 (vertical).



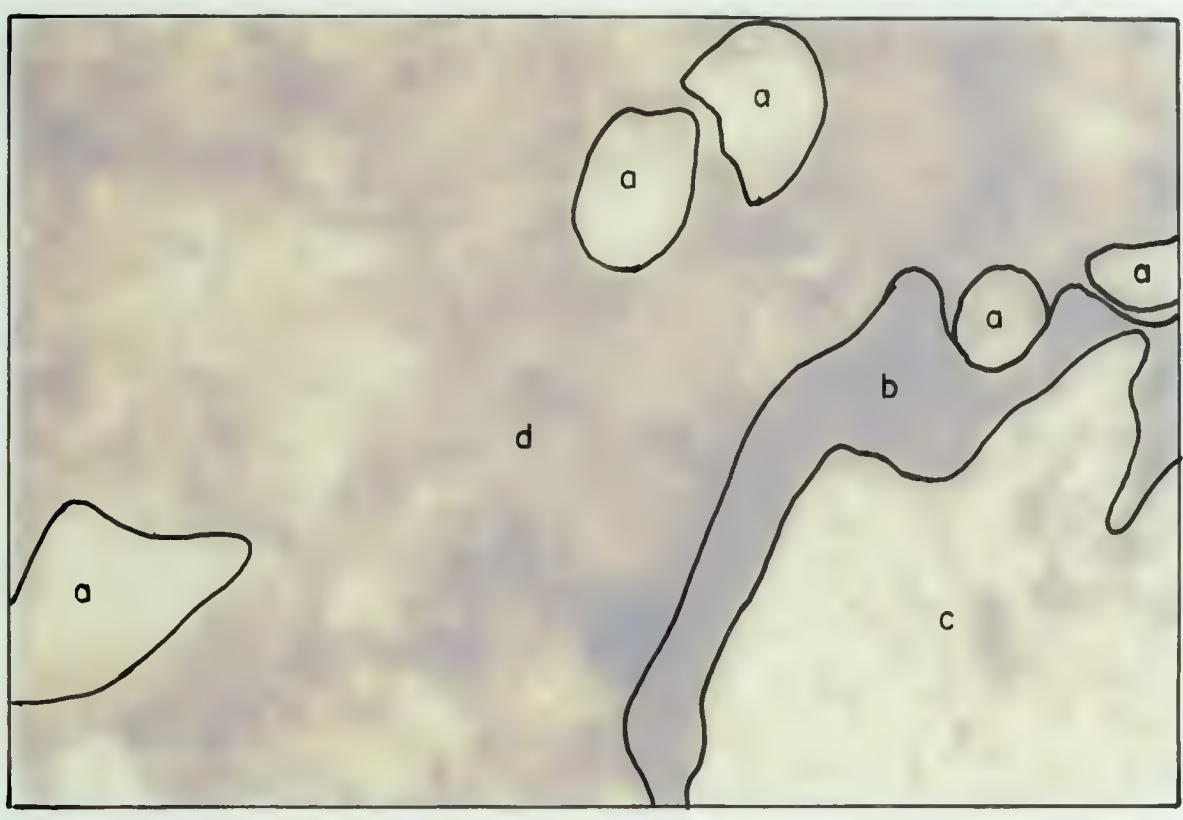


Description of Plate 11

Some of the larger scale characteristics of the bottom band, in the profile at site 3, are depicted by Plate 11. There are horizontal discontinuous bands of greyish to brownish material and other bands of reddish material in thin sections from this band. There are also spots of greyish to brownish and other spots of reddish material as indicated in the bottom center of the picture. Both colors differ from the color of the matrix. DeMent (1962) found similar manifestations of fabric in some thin sections from banded soils in Alaska. Thin sections often contain spots or blotches of redder or greyer colored materials in a background of fairly uniform color. The greyish material appears to be eluviated of iron while the reddish spots appear to be accumulation of iron. The greyish spots appear to retain some organic matter. This may suggest individual movement of organic matter and iron immediately before deposition.



Schematic Diagram of Plate 12

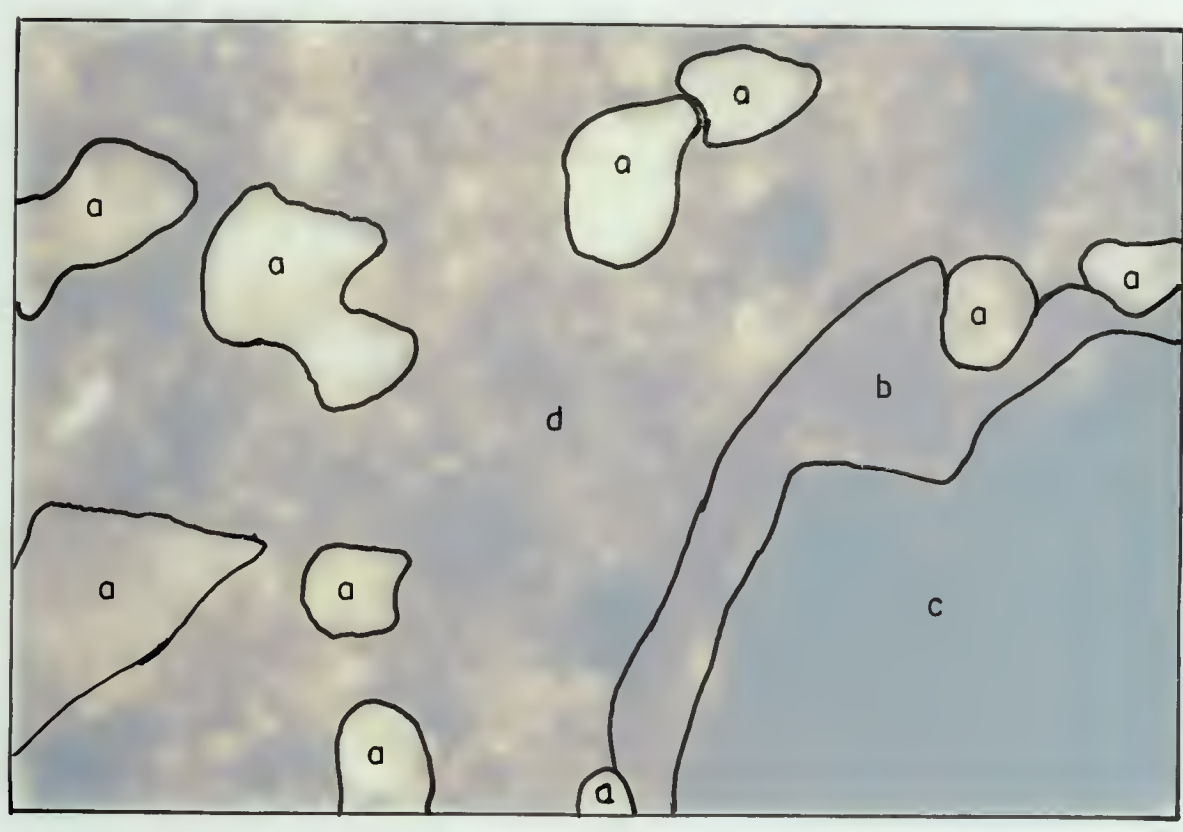


Polarized  
light

LEGEND

- a) Mineral grains
- b) Layered cutan
- c) Void
- d) Matrix

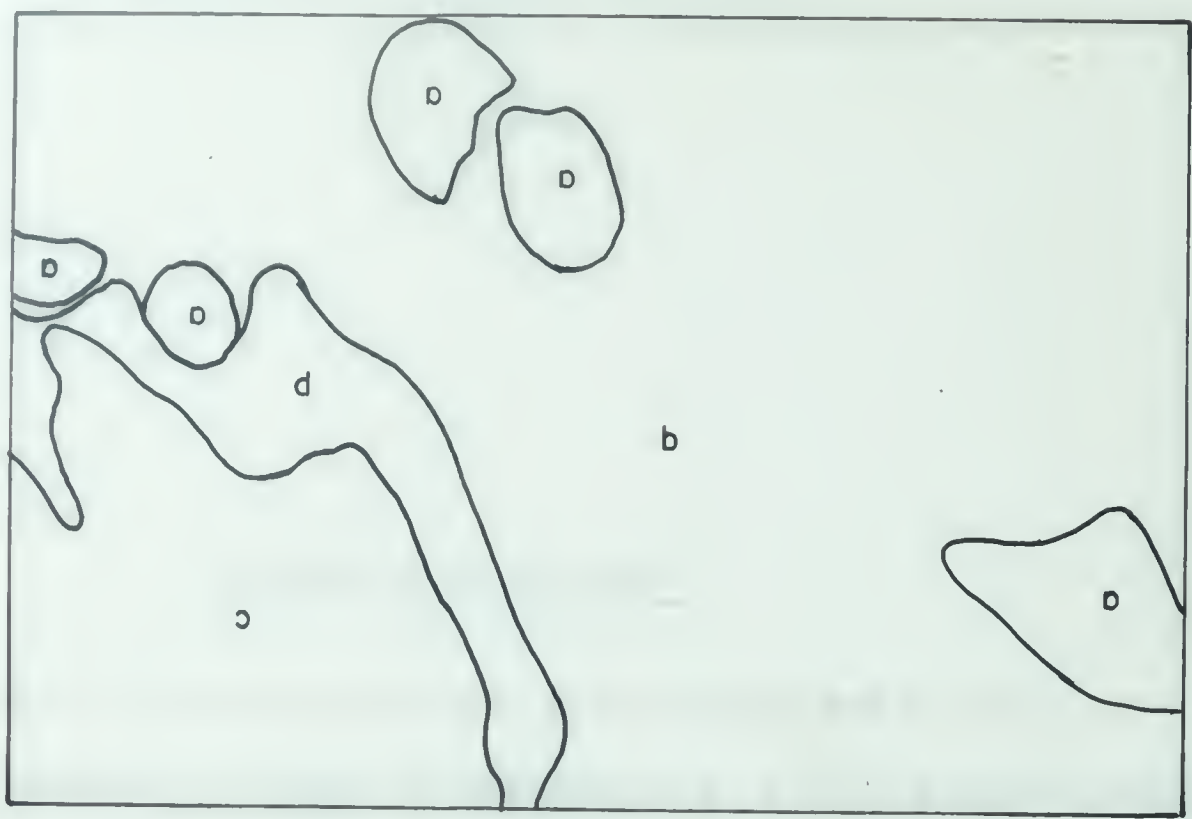
0.42 mm.



Crossed  
polarizers

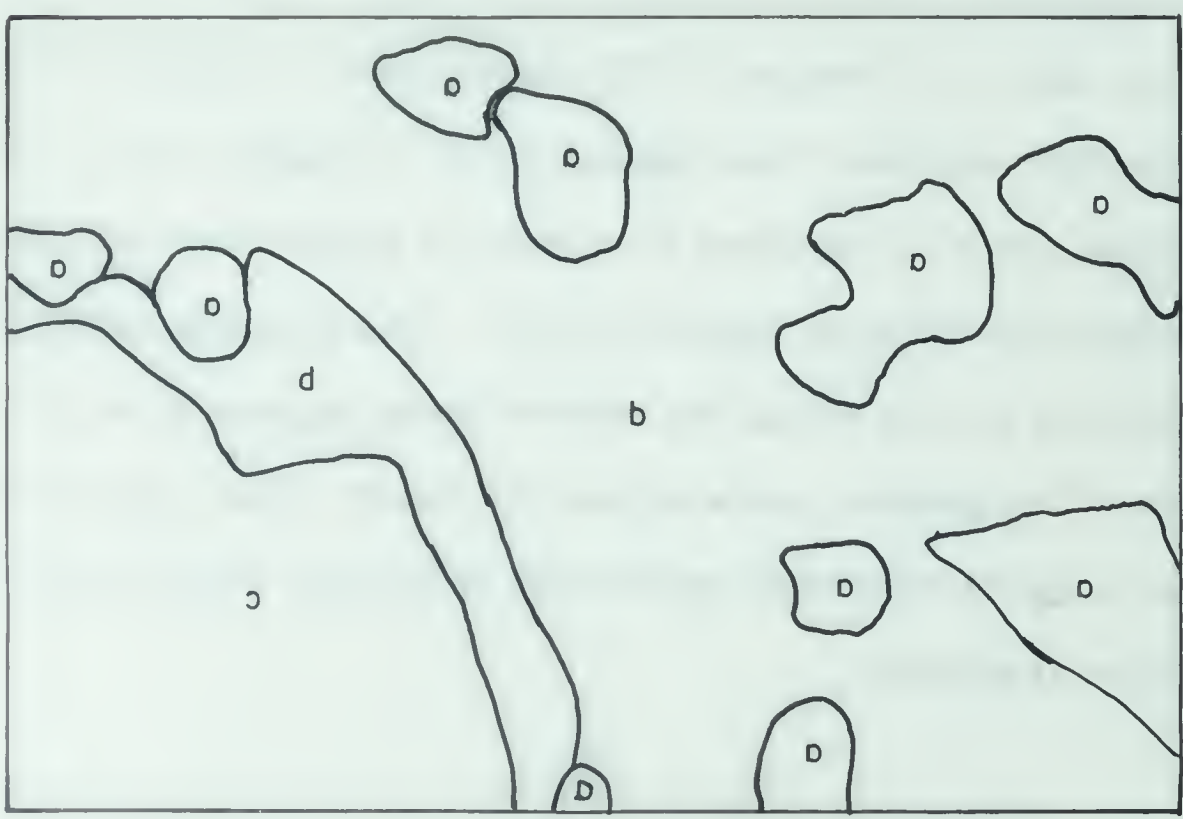
Plate 12 Photomicrograph of the 4<sup>th</sup> sand, section no. 3100 3 (horizontal).

Schematic Diagram of Plate 12

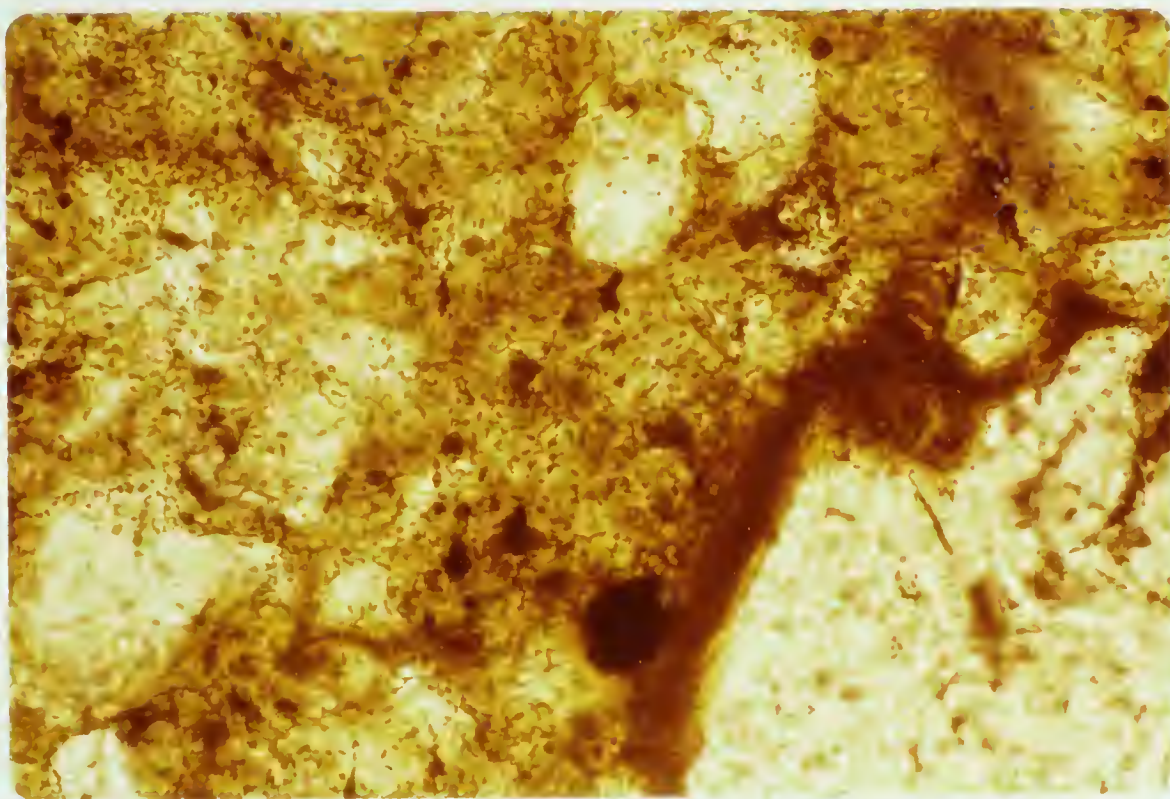


LEGEND

- a) Mineral grains
- b) Layered cuton
- c) Void
- d) Matrix

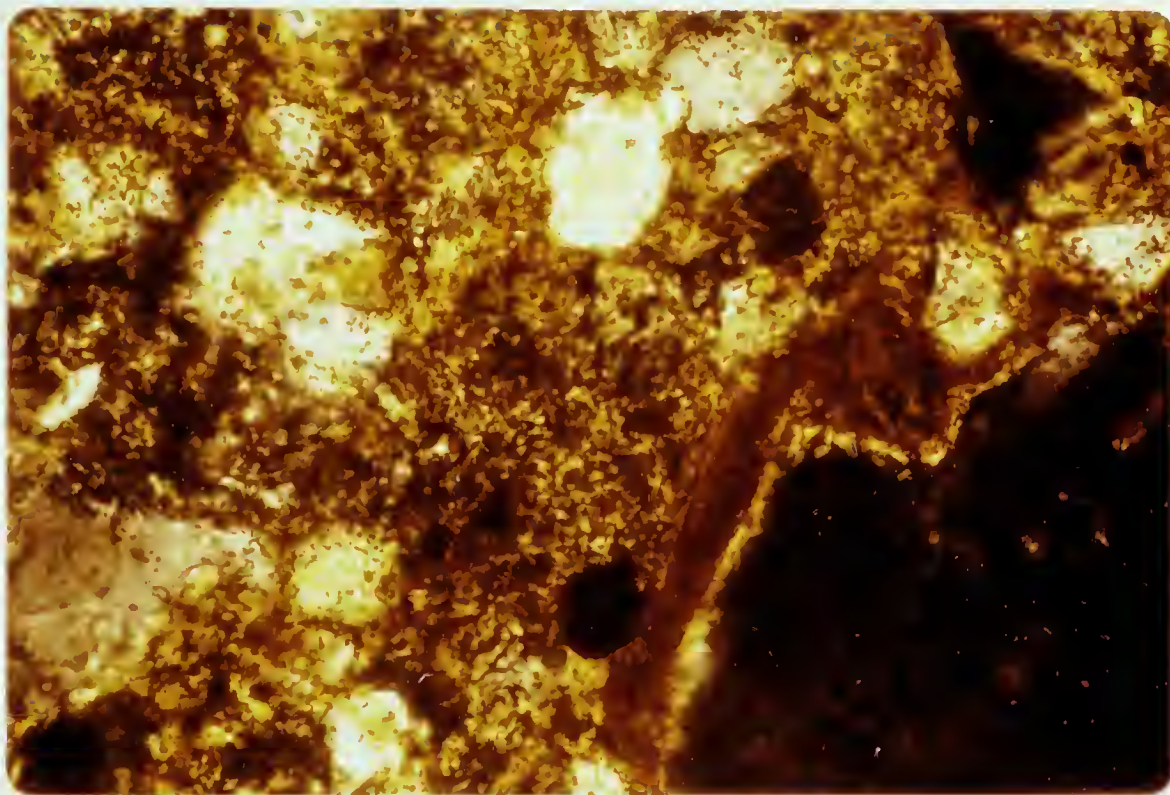






Plane  
Light

← 0.42 mm. →



Crossed  
Polarizers

Plate 12. Photomicrograph of the 4<sup>th</sup> band, sampled at Site 3 (horizontal).



Description of Plate 12

This photomicrograph of a thin section sampled in the 4th band (from the top) at site 3 indicates that illuvial clay forms part of the fabric of the band. The well formed oriented clay-iron cutan may be considered as a good indication of illuvial clay. The fabric is similar to the porphyrokelic fabric described by Brewer (1964). Cutans of this nature were found throughout the profile at site 3. At site 1 and site 2 the coatings were mainly on the mineral grains but they were not isotropic indicating some oriented clay.





In addition to fabric and particle size distribution variations there were also variations in color of the sections in plane light. Blotches of grey material and blotches of reddish-rusty material both of which occurred in a brownish groundmass, were only a fraction of a mm. apart.

In the "Ae-like" material of site 2 the intertextic-granular fabric is quite evident with little else present other than voids and mineral grains. In this material there is a prevalence of opaque material consisting of both amorphous iron and organic matter. It is likely that their fluffy appearance is a result of co-precipitation of iron oxides and organic materials.

Specimens for microscopic examination were prepared with both horizontal and vertical orientations. In general horizontally oriented thin sections show more cutans than do the vertically oriented thin sections prepared from the same material. Channels in the soil are generally predominantly vertical and thus more voids, conducive to cutan formation, would be expected to occur in horizontal or cross-sections than in vertical sections which may pass largely between the channels.

The thin sections of all the samples examined show a difference between the band and the material above or below the band. The bands have more cutans on the void surfaces and/or mineral grains than do the interbands. The cutans are redder than the rest of the soil material and appear to be composed largely of iron oxide, although in some cases there is a considerable amount of oriented clay included. Bands from the upper sola have the thickest and most continuous cutans. Microscopic variations between bands and interbands are less obvious





at lower depths in the profiles although macroscopically the bands remain distinct.

Some vertical thin sections include both interband and band material. In one instance there is a distinct break between the band and interband, although differences are not large.

Thin sections representing site 1 and site 2 are nearly devoid of cutanic materials in the interbands while the bands show only thin cutans some of which include oriented clay. Bright lines around the mineral grains are considered indicative of optically oriented clay (Brewer, 1964).

In the thin sections prepared for site 3 the cutans are often of considerable thickness, generally continuous and often show evidence of oriented and layered clay materials. Since the profile at site 3 is generally finer in particle size distribution than at site 1 or site 2, there is comparatively more clay available for cutan formation than in the first two sites. It is possible for oriented cutans to form in situ in profiles with high clay contents (Buol and Hole, 1959) but in these profiles the in situ orientation of clays is unlikely, because the profiles are all relatively coarse textured resulting in only small amounts of clays available for in situ orientation without eluviation.



## V. CONCLUSIONS

Mode of Deposition of Parent Materials: Field observations in the sampling area suggest an aeolean overlay may cover the area. Well developed or deep Ae horizons in Central Alberta are generally found under Ah horizons which are shallow or indistinct. However, in the sampling area deep Ah horizons are commonly found on top of deep horizons which have the morphological characteristics similar to that of an Ae. Thus these "Ae-like" materials have been considered by some workers as aeolean materials. The aeolean concept is supported by the observation of obvious stratification only in the material below the "Ae-like" material.

Mechanical analyses show that at site 1 there is considerable stratification throughout the profile which might be attributed to wind and/or water. There is generally, in site 1 and site 2, a maximum concentration of particles in the 0.25 to 0.10 mm. in diameter size fraction. Doeglas (1945) suggests that aeolean materials should show a maximum concentration of particles between 0.08 and 0.02 mm. in diameter. Bagnold (1954) suggests that the maximum concentration of wind blown sands is never less than 0.08 mm. and is generally between 0.15 and 0.30 mm. in diameter. Doeglas (1945) was discussing aeolean materials which were carried by suspension and thus similar to loess while Bagnold (1954) was considering materials predominantly of the size moved by traction and saltation, therefore the apparent contradiction is explained. In studies on wind erosion of soils, Chepil (1960) has shown that the most erodable (wind) particle is around 0.1 mm. in diameter. Chepil's work has been primarily related to the evaluation of erosion surfaces, thus his work is not particularly applicable to a study





of particle deposition. The most erodable particle as found by Chepil (1960) is somewhat smaller in size than that found by Bagnold (1954) for wind blown sands. Wind variations, position, and type of source material as well as other factors may result in deposition of particles with varying diameters in maximum concentration for different areas. Therefore, the materials examined in this study may have been wind worked to a greater or lesser degree.

The soils at site 1 and site 2 were likely wind worked to some degree. However, site 3 has a maximum concentration of particles in the silt size which may have been either deposited from suspension in wind or possibly from suspension in water.

Grain frosting is evident throughout the three profiles suggesting that the sands were worked by wind sometime before or during deposition. Grains in the very fine sand fraction become frosted almost exclusively by wind action (Twenhofel, 1945). However, such sands may be carried relatively short distances in water before being deposited without losing their frosting.

The X-ray diffraction patterns show that there is appreciably more montmorillonite in the A & B horizons than in the A horizons. In addition chlorite is not evident in the A & B horizons but is present in the A horizons. Chlorite-montmorillonite or chlorite-illite-montmorillonite mixed layer clays are present in the A horizons while illite-montmorillonite mixed layer clays are found in the A & B horizons. The shape of the glycolated montmorillonite peak is much broader in the "Ae-like" material than in the A & B horizon indicating poorer crystallinity in the former material. The variations in X-ray diffraction patterns may be either the result of weathering or the result of



mineralogical stratification. It has been shown that the finer clay particles move preferentially and that the fine clay fractions have broader X-ray diffraction peaks as a result of poorer crystallinity (Lavkulich, 1963). Weathering in the profiles studied would likely be accompanied by clay eluviation, and since better crystalized montmorillonite was found in the A & B horizon than in the "Ae-like" material, then weathering is unlikely to be the cause of the differences noted. The chlorite, in the profiles at site 1 and site 2 particularly, appears to be relatively unweathered. It is felt that the amount of weathering as indicated by light mineral analysis is not sufficient to have caused the changes evident between the clays of the "Ae-like" materials and the A & B horizons. Thus, the X-ray diffraction patterns of the clays suggest that the clays in the "Ae-like" material are of different mineralogy than those of the subsurface material. The method of deposition of the surface material, however, seems to be no different than that of the subsurface material.

The characteristic sharp peaks illustrated on the particle size frequency distribution curves (Figures 6, 7, and 8) as well as grain frosting (Plate 3) suggest that these materials have undergone sorting by wind. However, the variable stratification as well as particle size frequency distribution curves which are highly skewed toward the silt region suggest that water action has also been active. Also the presence of a gravelly contact at site 1 suggests that water, at one time, must have covered the area.

On the basis of particle size frequency distribution curves and cumulative curves some of the materials seem to have been deposited by wind. Actively eroding areas forming miniature dunes are found within 1/2 a mile of site 1 suggesting that these materials are readily





moved by wind. It is probable that water covered this deltaic region at the time of deposition and therefore wind blown sands from the glacier could have been deposited on the water surface in association with the water transported sands which formed the delta.

The "Ae-like" horizon or "aeolean-like capping" appears to be nearly uniform in thickness at the tops of hills and on the lower slopes. The clay mineralogy of this material is also different than the clay mineralogy of the material in the lower solum. Thus the "Ae-like" material was probably transported by wind and was either deposited on the water surface or the drained delta surface, after the exposure of a different clay mineralogical source area.

Genesis of Bands: The desire to ascertain whether the bands in the profiles of the sampling area were geologic or pedogenic and thus aid in the classification of these soils was the main reason why this study was initiated. The bands may have been layed down by stratification during geologic deposition and remained relatively unaltered to the present. Alternatively, the bands may have been formed entirely by pedogenesis from a uniform geologic parent material. These two concepts are not mutually exclusive and thus both processes may have been responsible for the band formation.

Mechanical analysis suggest that geologic stratification is present at the three sampling sites. The soil profiles at site 1 and site 3 show considerable stratification but it is less evident in the profile at site 2. Heavy liquid separations of the sand fraction of 0.10 to 0.15 mm. in diameter also suggest that mineralogical stratification exists. Further evidence of stratification is suggested by the X-ray diffraction patterns which indicate a mineralogical difference





above the first band as compared to the solum below the "Ae-like" material. Microscopic analyses also suggest that geologic stratification is present. These factors provide evidence which favor a geologic origin for the bands.

Chemical analyses indicate that pedogenic illuviation and eluviation of organic matter and iron oxides has occurred to an appreciable degree. This suggestion is supported by the presence of iron and clay-iron cutans as shown by petrographic microscopic analysis.

Thus both geologic deposition and pedogenic eluviation and illuviation are likely active in band formation. The fact that the most prominent, best defined bands are in site 2, which is the site where geologic stratification is at a minimum, suggests that geologic stratification is not necessary for band formation.

Morphological observations have shown that bands sometimes transgress geologic strata, although in such instances the bands are generally waning or fading out. In general, the bands tend to follow the contour of the soil surface although fine branches are occasionally observed migrating from the main band upward well into the "Ae-like" material. Since the bands tend to coincide with stratification changes, when present, it is likely that they follow stratifications at least in the horizontal direction. Geologic stratification is known to cause a change in percolation rate thus resulting in precipitation of colloids at that point (Bartelli and Odell, 1960). The branches migrating toward the surface from the main band are probably purely pedogenic. The premise that the bands usually follow geologic stratifications is borne out by the fact that bands often occur as part of the strata regardless of the divergence sometimes noted in two adjacent strata.



Analysis of the data determined for the profile at site 1 indicates that a single textural stratum is occupied by both the top band and the interband material immediately below. Thus, the tendency for bands to follow geologic strata does not indicate that the bands occupy the entire strata in which they are found. Also sample 5 in the same profile was of strata texturally different from sample 4 or sample 6, yet no band was initiated in sample 5. Therefore, every change in strata does not initiate a band.

It appears as though when conditions are conducive to band formation the bands form irrespective of whether or not geologic stratifications are present. If conditions are not proper for band formation the band does not form in spite of stratification. However, if stratification is present and the conditions are correct, then the stratification may act as a center for band formation.

The bands in the profiles at site 1 and site 3 as well as many other profiles in the area conform to the contour of the soil surface. This would be expected if the bands tend to follow geologic strata.

The bands in site 2 are nearly parallel to each other, and are nearly horizontal (Figure 4) while the soil surface is more steeply sloping. This profile has little evident stratification as shown by mechanical analysis and microscopic examination. An area of similar profiles was noted to the south of site 2. It is possible that the depth of percolation at least in part influences the depth at which bands form in profiles which are not influenced by geologic stratification. Thus, as the slopes become steeper, surface runoff increases resulting in shallower percolation and the formation of bands closer to the surface.





There are three possible sequences in which bands in this study may have formed:

- (1) The bottom band forms to completion and then another band is developed above it with this sequence of events being repeated until all the bands are formed.
- (2) The top band forms to completion and then another band is initiated below it and forms to completion, with this sequence of events being repeated until all the bands are formed.
- (3) Development of all the bands is concomittent.

It is felt that in the area studied a fluctuating water table could not have formed the bands because it is unlikely that the water table could be found at the tops of the fairly sharp, sandy knolls. This is supported by lack of gleyed and/or mottled horizons.

The first sequence is unlikely because in periods of low precipitation percolating solutions would not reach the bottom band and thus suspended materials would be immobilized above this band. Even if these dry periods were followed by periods of greater precipitation, the percolating solutions would likely have in suspension all the materials they would be capable of carrying and thus would be unable to resuspend all the previously immobilized material to carry it the remainder of the way to the actively forming band.

The second sequence is unlikely because even if all the materials were immobilized in the first band the percolating water could pass through the band and suspend or dissolve material from the portion of the profile below the first band with a subsequent deposition of these materials at some lower level.

The simultaneous development of bands or the formation of a continuous B horizon would be the result if, as in the first case, the



suspended materials were immobilized before reaching the bottom band or, as in the second case, the waters after percolating through the band become recharged with materials. Thus, in banded profiles the simultaneous development of the bands appears to be the most reasonable sequence for band formation.

The profiles observed in this study indicated that thick bands were often found deep in the profile while the upper bands were generally thinner. Below the top band the thickness of interband from which percolating solutions can eluviate materials is always thinner than the eluviated layer above the top band. By the photographs included by Folks and Riecken (1956) it can be seen that the soils they studied showed a similar trend.

The BC or lower Bt horizon in many Grey Wooded soils has been shown to have as much or more accumulated clay than the upper Bt horizon (Pawluk, 1961; Lavkulich, 1963). Therefore, under some conditions clay will move downward through a zone of illuviation. Thus, clay may be expected to move through a thin zone of illuviation such as the top band in a banded profile. Also in porous soils the filtering action of accumulated materials in the band regions would probably not be sufficient to remove all the materials from suspension. Therefore, lower bands probably would also reflect an accumulation of some of the material from above the top band as well as material from the interband regions. Microscopic analysis indicates that the lower bands have a lower quantity of oriented clay than upper bands of equal thickness.

Organic carbon in the bands does not decrease with depth. However, in site 2 the top and the bottom bands were sub-sampled in a manner which separated the upper and lower portions of the bands. Organic carbon was determined for both samples. In the top band the





upper and lower samples had the same carbon content. In the bottom band the upper sample contained more carbon than the lower sample.

The field morphological evidence plus the laboratory analyses indicate that at least some materials are able to move through the top bands to be deposited in the lower bands.

Many suggestions as to the exact precipitation mechanism for the formation of multiple bands have been made (Folks and Riecken, 1956; Wurman et al., 1959; DeMent, 1962). In situ formation of the bands has been suggested (Wurman et al., 1959) as one possible mechanism of band formation. In the profiles studied the extent of weathering could not account for the amount of clay, iron, or organic matter accumulated in situ.

Suggested possible mechanisms for precipitation and retention of colloidal materials in the bands are:

- (1) Adsorption on colloids in the bands where they occur in higher concentrations.
- (2) Redox conditions causing colloids to be precipitated in the bands.
- (3) pH conditions causing colloids to be precipitated in the bands.
- (4) Concentrations of divalent cations causing the colloids to be precipitated.
- (5) Filtration of materials out of suspension in percolating solutions by geologic strata with textural variations.
- (6) Immobilization caused by microbial decomposition of protective organic complexes.

It is evident that the colloids can not be carried farther through the profile than the percolating solutions penetrate, but this does not necessarily mean that immobilized colloids are retained in that position. However,





it would seem that the depth of percolation must influence other mechanisms active in band development. A filtration mechanism is suggested to be active in these soils but it is probably not the only active mechanism. This study does not provide information which explains the exact mechanism of precipitation nor why the precipitation occurs in bands rather than as a single B horizon.

The nomenclature used in this study to designate the band-interband regions is that suggested in the "7th Approximation". The definition of an A & B horizon is a "horizon which would qualify for an A2 (Ae) except for included parts constituting less than 50 per cent of the volume that would qualify as B". The Canadian Classification recognizes the possibility of an A & B horizon but does not describe it as rigorously. It is misleading to designate these horizons as the sequence Ae, Bt, Ae, Bt, etc. because no provision is made for the isolated patches of B horizon material and the "pipes or doughnuts" mentioned earlier. The region between the A and the C horizons is an interlayering of materials characteristic of both A horizons and B horizons but the bands are not sufficiently developed to be designated as Bt or Bf horizons as set forth by the Canadian Classification Scheme. After considering these reasons the horizon designation as suggested by the "7th Approximation" was felt to be the most appropriate.

In this study the greyish material below the Ah horizon and above the top band has been referred to as "Ae-like" material. This material has been shown to be eluviated and thus it is probably best designated as an Ae horizon regardless of the lithologic variations within or beneath it.

The Ah horizons in these soils are generally well developed and often appear to be 8 to 12 inches in thickness although wind action may



have increased the thickness in local areas. The Ah and/or Ahe horizons in these soils have color criteria which are the same as found in Dark Grey Chernozemic soils. (Site 2 meets the minimum criteria for Black Chernozemic soils.) In some cases the Ah is covered with a leaf mat, as in site 3. The Ae horizons in these soils are well developed and are often 30 to 35 inches in thickness. A transitional AB horizon is, in most cases, absent. The A & B horizons have a considerable accumulation of free iron and organic matter in the bands as compared to the interbands. However, color criteria do not allow the horizons to be designated as Bf horizons and sufficient organic matter is not present for Bh horizons. Clay accumulation is evident in several of the bands but if taken individually none of the bands meet the requirements for a Bt horizon as set forth in the Canadian Classification Scheme. Whether or not the bands are to be considered individually or collectively in evaluating criteria for a Bt horizon is not clearly stated in the definition. However, according to the definition for Grey Forested soils it would appear that each individual band is considered to be a separate B horizon. Therefore, neither Bf, Bh, nor Bt horizons are considered to be present.

The interbands of some of the soils studied also appear to contain small splotches of illuvial clay and iron resulting in a mottled appearance. The sola are acidic throughout but are also highly base saturated. Calcium carbonate is generally absent even at considerable depths below the sola in these soils.

These soils do not fit particularly well in any of the existing categories set forth in the Canadian Classification Scheme. The Ah horizons in these profiles suggest that they should be classified in the Chernozemic order. However, the lack of calcium carbonate in the





materials below the solum may also be considered contrary to the development of Chernozemic soils. In addition, Chernozemic soils with well developed Ae horizons also have Bt horizons in the profile sequence. Thus, on the basis of the deep Ae and the lack of Bf or Bt horizons the profiles examined appear to conform more closely to the Dark Grey Forested soils. It is felt, however, that rather than being regosolic in nature, thus as intergrade between Regosols and Grey Wooded soils, these soils are intergrades between Chernozemic and Grey Wooded soils but rather than having continuous Bt horizons these soils are characterized by discontinuous illuvial bands.



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